

CSC 2015

Exploring the Material Conditions of Learning

The Computer Supported Collaborative Learning (CSCL) Conference 2015

Conference Proceedings Volume 1

Edited by

Oskar Lindwall Päivi Häkkinen Timothy Koschmann Pierre Tchounikine Sten Ludvigsen





Exploring the Material Conditions of Learning:

Computer Supported Collaborative Learning (CSCL) Conference 2015

Volume 1

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Conference logo and cover design by Thomas Hillman

Preface

The University of Gothenburg is hosting the 11th International Conference on Computer Supported Collaborative Learning from June 7 to June 11, 2015. The conference is part of the International Society of the Learning Sciences (ISLS). ISLS is a professional society dedicated to the interdisciplinary empirical investigation of learning as it exists in real-world settings and to how learning may be facilitated both with and without technology. The CSCL conference has an explicit focus on how and why computer support can enhance learning processes and outcomes. The CSCL field brings together researchers from cognitive science, educational research, psychology, computer science, artificial intelligence, information sciences, anthropology, sociology, neurosciences, and other fields to study learning in a wide variety of formal and informal contexts (for more information see www.isls.org). It emerged in the late 1980s and early 1990s. Before the establishment of the biannual conferences, there was a NATO-sponsored workshop in Maratea, Italy in 1989 and another workshop sponsored by Xerox PARC in 1991 at Southern Illinois University. The first international conference was held in 1995 at Indiana University, followed on a more or less biannual schedule by conferences in Toronto, ON, Canada (1997); Maastricht, Netherlands (2001); Boulder, CO, USA, (2002); Bergen, Norway (2003), Taipei, Taiwan (2005); New Brunswick, NJ, USA (2007); Rhodes, Greece (2009); Hong Kong, China (2009); Madison, WI, USA (2013). There is also a scholarly journal, the International Journal of Computer-Supported Collaborative Learning, and a book series published by Springer.

Acceptance rates for each category of submission to this year's conference:

36 % for full and short papers 46 % for symposiums and panels 45 % for posters

The program reflects a broad geographic representation from 31 countries and 6 continents. Reviews were solicited from 373 reviewers producing 848 reviews. A senior reviewer was assigned to each paper, symposium, and panel proposal and they prepared meta-reviews for each submission.

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Exploring the Material Conditions of Learning: An Introduction to the Computer Supported Collaborative Learning (CSCL) Conference 2015

Within the learning sciences, the field of Computer Supported Collaborative Learning (CSCL) has continually raised the importance of the material conditions of learning. Reinvigorating this focus in a time of rapidly expanding forms of social, cognitive, and technical mediation is particularly important. The proliferation of digitized information, the affordances of digital technology, and the current changes in media ecology affect society at all levels. Not only do these material conditions influence the way we learn or what is considered relevant knowledge in the many social contexts of our lives, they also set the premises for how knowledge is formed and how it is organized, made use of, and communicated. Changing patterns of collaboration, authority, and legitimacy of knowledge in society and its institutions have important implications for learning and cognitive processes and outcomes, and these changes are consequential for education, production, social administration, and the public.

The material conditions of learning have been explored in numerous ways, including, but not limited to: basic research of collaboration, learning processes, knowledge formation, and media ecology; applied research and design studies of how specific tools, applications, and activities are used and modified for the benefit of relevant fields of practice; and theoretical approaches to the development of the interdisciplinary fields of CSCL and the learning sciences and their manifestations in society. It is clear that the field of CSCL includes different approaches and methodologies. This variety is of course nothing new, but it is important to recognize and appreciate. High quality contributions are important for the field and are not dependent on which perspective or approach upon which they build. The multifacetedness of the field is in this sense a characteristic as well as strength.

When working with the submissions and the creation of the program, some trends have emerged. Collaborative knowledge building continues to be an important area of scholarship within the CSCL community. Many research groups and scholars around the world take the seminal work of Bereiter and Scardamalia as a starting point. The idea of collaborative knowledge building is not only applied to new contexts but also extended in different directions. Some specify the knowledge building of individuals while others look at how collaboration emerges over time. Argumentation as a specific form of collaboration has also become an important theme in the field – either as part of collaborative knowledge building or as a perspective on its own.

How scaffolds for learning are built and organized are classic issues in the field. More recently, concepts like scripting and orchestration have also become important. Designs built on scripting and orchestration give us new insight into how groups and whole classes interact and work to undertake specific tasks and solve problems. In this work, collaboration is sometimes conceptualized as multiple paths of joint work in which both individual students and the larger community benefits. Within the papers of this volume, the notion of communities of practice is used both as a metaphor and as the foundation of a perspective. As digital environments become increasingly important to our everyday lives, it is clear that the context of learning plays a central role. The importance of context, however, does not direct the focus away from the issue of collaboration. To be able to constitute a community of practice, smaller units like dyads and groups clearly need to work in productive ways.

Over time the topic of embodiment has grown to be an increasingly important consideration in cognitive studies, philosophy of language and in education generally. It was perhaps inevitable that it would become an explicit theme for research in CSCL as well and we see evidence of that in this year's program. When it comes to new technologies, it is noticeable that tangibles and tablet-based collaboration have become central scaffolds and contexts that support and enhance learning. Tangible interfaces have also enabled embodied interaction with computational objects in our physical world.

Another research strand that now has a clear presence in the CSCL community is the study of games and epistemic games. Epistemic games are designed specifically for learning and often share some design features with simulations. With regard to the recent attention of games, it is important that researchers in the field raise questions that go beyond the hype and critically investigate what people/students learn when they play games.

Similar arguments can be made about social media. It is interesting to see how social media platforms and community services can include designs that support different types and forms of collaboration.

Participation and dialogue have also gained increasing attention in massive open online courses (MOOCs), and hence, collaborative learning in MOOCs has also become a focus of research in the CSCL community.

A rather new theme for the CSCL community is learning analytics. As platforms, design, and technological features have become more advanced and data produced automatically, analytics has emerged as an important resource and topic. A key question in the field of learning analytics is the nature of the data that can help us to describe, understand, and explain learning processes and outcomes in more sophisticated ways. It is here clear that the combination of analysis of behavioral features with processes of meaning making and learning outcomes needs to be explored by multiple approaches.

In these volumes, you find a wide variety of papers that cover these themes and more. We very much look forward to continue the conversations about these issues at the conference. We would also like to express our deepest gratitude to the many people who made the conference possible: the organizing committee, the advisors, the senior reviewers and the reviewers, the local organizing committee, the sponsors, volunteers, the staff, and all the presenters and participants. Your contributions make the CSCL field a thriving field that change learning opportunities that can enhance people's participation and engagement in new and emerging activities in the society.

Finally, we would like to offer a special thanks to Laura D'Amico for the care and thoroughness that she brought to the task of putting the proceedings to order over the past several months. The construction of a conference proceedings tends to be a thankless job, but we would feel remiss, if we left it so. These completed volumes are a testament to her hard work and we are deeply grateful.

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Understanding and Encouraging Communication With Visualization

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Abstract. Face-to-face communication requires a complex orchestration of various communicative channels that include gaze, gesture, expression, and vocalization. Visualization can highlight this invisible dance; it can also encourage and discourage specific communicative behaviors. In this talk, I will present a trajectory of visualization work starting with the visualization of vocalization and moving towards the visualization of coordinated communicative behavior. In doing so, I will discuss the challenges faced when aggregating disparate streams of data, discuss when visualization is helpful, and pose the question: how does visualization translate to cognition?

Mundane Governance: Government by Stealth?

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Abstract: Popular conceptions of "government" tend to rely on a notion of politics which involves how people and institutions behave towards each other. Yet another, quite different, and much more pervasive form of government is often overlooked. This has to do with the way in which our lives are increasingly regulated in relation to very ordinary objects and everyday technologies. These aspects of daily life are mundane in the sense that they are ordinary, routine, unremarkable, run-of-the-mill, even boring. More interestingly, they are also mundane in the etymological sense of the term (latin: mundus: the world): these ordinary things seem to be just what they are: they are "of the world". Our research focused on three main areas of contention about ordinary objects and technology: the organisation and categorisation of different varieties of waste and recycling; the ways in which vehicles are subject to speed monitoring and parking regimes; and the management of passenger flow through airports. In short, we studied trash, traffic and transit.

We found a growing disquiet, often marked exasperation, about the increasing complexities of ordinary stuff. Now more than ever we seem to be governed through the small everyday routines, actions and objects by which we are surrounded. The problem gains particular significance when we notice that the same ordinary things are treated quite differently in different places, councils, regions and countries.

This then is the government you don't realise is all around you. Increasingly, it seems, ordinary, unremarkable stuff carries with it requirements for correct action and behaviour. Can we call this "government by stealth"? This description rather too easily implies a form of conspiracy theory; it suggests concerted and coherent strategies on the part of faceless bureaucrats eager to control the unknowing populous. Instead, our observations of mundane governance in practice reveal a striking degree of mess and muddle. So instead of a coherent system of government conspiracy, we find a chaotic amalgam of shifting uncertainties and complexity. Regulation in relation to ordinary things is, at best, a mess. To understand this we need a different approach to politics. Politics can no longer be thought of as simply antecedent to objects which are fixed and known; instead, we need a conception of politics which recognises the crucial importance of understanding how ordinary objects and things come to seem what they are.

Suspense Matters

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Abstract: Piaget is often cited for writing that when you teach children something you take away forever their chance of discovering it for themselves. This observation is profound in view of the modern academe's push towards ever more personalized learning, where the focus of much technology development is on measuring, rectifying and rewarding activity completion. How can we bring back the 'not knowing' in learning where suspense is what matters? In my talk, I will consider how new technologies and interfaces can be designed to enable children to discover for themselves, through mindful engagement, awareness, conversation and reflection.

Presidential and Invited Sessions

CSCL 2015 Presidential Session: Grand Challenges in Technology-Enhanced Learning

Eleni A. Kyza (Chair), ISLS President 2014-15, Cyprus University of Technology

Carolyn Penstein Rosé, ISLS President-Elect, 2015-2016, Carnegie Mellon University, USA Cindy Hmelo-Silver, ISLS Past-President, 2013-2014, Indiana University, USA Cynthia D'Angelo, SRI International, USA Katherine Maillet, Télécom Ecole de Management, France Ben du Boulay, University of Sussex, U.K. Beverly Woolf, UMass-Amherst, USA Dragan Gasevic, University of Edinburgh, U.K.

Christopher Hoadley (Commentator), New York University, USA

Abstract: The ISLS Presidential Session at CSCL 2015 is about Grand Challenges in Technology Enhanced Learning (TEL). The Grand Challenges concept has been discussed in different contexts and across the continents: it helps identify ambitious spaces where we want to venture but which still present obstacles; at the same time, grand challenges are windows into a future that we can shape. Grand challenges are inherently complex; immensely promising; require interdisciplinary approaches; and transcend national and cultural contexts. At the same time, their outcome is risky and presents uncertainty.

Keywords: grand challenges, digital resources, technology-enhanced learning, presidential session

Intelligence is the ability to adapt to change. Stephen Hawking

Session overview

Grand Challenges in Technology Enhanced Learning are full of promise for potential impact and can be powerfully appealing to policy and the public. These challenges require new ways of thinking and demand innovation as they seek to bring about change. In short, we do not simply seek to simply understand better, fine tune, or be tied to what is, but rather we seek to envision and then bring forth positive change.

The CSCL 2015 Presidential Session is the outcome of an ongoing collaborative effort among several professional Societies to consider the grand challenges related to technology-enhanced learning; six of them will be participating in this joint panel. Between March and May of 2015, this interdisciplinary panel has sought to engage the members of seven Societies, all deeply entrenched in TEL research in an interactive exchange of ideas about the most notable grand challenges conceived as a result of recent advancements in science and technology.

This interactive panel session will provide the opportunity to representatives of these Societies to present thought-provocative position statements, to be followed by, what we hope to be, a lively interaction among the CSCL 2015 attendees participating in this session. The results of the session will be available online and will constitute the basis of future efforts among these Societies to collectively identify the Grand Challenges in Technology-Enhanced Learning.

Panel participants

Chair Eleni A. Kyza, ISLS President, Cyprus University of Technology

Panel members

Representing the International Society of the Learning Sciences (ISLS: http://www.isls.org/) Eleni A. Kyza, ISLS, President 2014-2015, Cyprus University of Technology, Cyprus Carolyn Penstein Rosé ISLS President-Elect, 2015-2016, Carnegie Mellon University, USA Cindy Hmelo-Silver, ISLS Past-President, 2013-2014, Indiana University, USA

Representing the Center for Innovative Research on Cyberlearning (CIRCL: http://circlcenter.org/) Cynthia D'Angelo, SRI International, USA

Representing the European Association of Technology Enhanced Learning (EATEL: http://ea-tel.eu/) Katherine Maillet, Télécom Ecole de Management, France

Representing the International Artificial Intelligence in Education Society (AIED: http://iaied.org/about/) Ben du Boulay, University of Sussex, U.K.

Representing Learning @ Scale (L@S: http://learningatscale.acm.org/las2015/) Beverly Woolf, UMass-Amherst, USA

<u>Representing the Society for Learning Analytics Research (SoLAR: http://solaresearch.org/)</u> Dragan Gasevic, University of Edinburgh, U.K.

Commentary

Christopher Hoadley, New York University, USA

Regulated Learning in CSCL: Theoretical Progress for Learning Success

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Summary

Recent theoretical underpinnings of successful computer supported collaborative learning (CSCL) have suggested that it is not only necessary to create environments that allow for learners to work together on complex problems requiring collaboration (i.e., where the benefits of working with others is greater than the transaction costs involved in communicating and coordinating actions; P. Kirschner, Kirschner, & Janssen, 2014), but where the communication and coordination are well regulated.

For collaborative learning to be effective, students must explicate their thoughts, actively participate, discuss and negotiate their views with the other students in their team, coordinate and metacognitively regulate their actions between them (Järvelä & Hadwin, 2013), and share responsibility for both the learning process and the common product (Fransen, Weinberger, & Kirschner, 2013). In collaborating, not only cognitive and metacognitive aspects of subject matter content play an important role, but also the social and meta-social aspects of collaboration (Puntambekar & Hubscher, 2005; Rienties, Tempelaar, Van den Bossche, Gijselaers, & Segers, 2009).

Despite extensive empirical research in CSCL, there is still little research about how groups, and individuals in groups, can be supported to engage in, sustain, and productively regulate collaborative processes. This may be due to overemphasis on developing and testing the functionality and usability of technology-based tools for sharing information or emphasized attention to the content related knowledge co-construction in CSCL. It may be also because of the variety of ways to conceptualize the concept of regulation in CSCL (Järvelä & Hadwin, 2013).

This symposium - an extension of the 2013 Special Issue in Educational Psychologist on the theories underlying CSCL and its use - introduces the ongoing new generation approach to theory building in CSCL; examining and clarifying the role of regulation in collaboration and pushing the discussion further. Papers examine aspects of socially shared regulation, regulative scripting, awareness tools to promote regulation and how multimedia environments can promote regulation. Each paper in the symposium: (a) specifically identifies what is regulated (e.g., task knowledge, own prior knowledge, goals and plans, strategic knowledge, motivation or emotions, etc.) in CSCL, (b) presents empirical findings to show how regulation emerges or influences collaboration, (c) identifies and discusses conditions under which regulation emerges and can be supported, and (d) identifies targets for future research about regulation in CSCL.

Looking at the major problems encountered when using CSCL as pedagogy, one can conclude that many of them might be solved if we would progress in concepts and tools that could help the participants in CSCL groups in the regulation of their working and learning within the group (Järvelä, Kirschner, Panadero, Malmberg, Phielix, Jaspers, Koivuniemi, & Järvenoja, 2014). Being able to strategically regulate one's own learning and that of others is a vital and increasingly important 21st century skill. This includes, for example, learners' ability to purposefully influence and adjust their own cognitive, motivational, and emotional behaviour as well as that of others for optimal learning and working (Zimmerman & Schunk, 2011).

In the symposium we have four leading research groups in the field of CSCL presenting their recent ideas and advancement of research on CSCL. Järvelä et al. will ground their conceptual advancement in self-regulated learning theory and they review their conceptual progress in (S)SRL research with accompanying CSCL regulation tools and empirical data examples. Fischer and Kollar discuss their Script Theory of Guidance (SToG) and how it provides a framework to explain how observable collaboration processes within a small group of learners is shaped by an interplay of learners' internal and external collaboration scripts. They broaden the framework from schema-theoretical and socio-cultural assumptions to more "social" covering the aspects of social regulation. Janssen et al. discuss their recent advancement in research on awareness in collaboration. They conclude that CSCL environments, and more specifically group awareness tools and supporting tools for teacher, have the potential to enhance students' regulation process. Lajoie et al. examine the theoretical assumptions that best describe the regulatory activities that occur in an on-line problem based learning (PBL) environment. Their introduce computer supported tools fo co-regulation, especially supporting teachers and learners on PBL activities. The two discussants, Kirschner and Hadwin will discuss the papers from two points of view, namely the methodological aspects of the research and the relevance of the research findings for learning and education.

Socially shared regulation of learning in CSCL: Understanding and prompting individual and group level shared regulatory activities

Sanna Järvelä, Allyson Hadwin, Hanna Järvenoja and Jonna Malmberg

The field of CSCL is progressing, both theoretically and practically (i.e., the design and development of tools and environments). Many successful advances have been achieved, for example, enhancing cognitive performance, stimulating knowledge construction and scripting collaborative interaction processes in CSCL (See Hmelo-Silver et al. 2013). Also less successful results have been received, especially in terms of problems on socio-emotional engagement (Näykki, Järvelä, Kirschner, & Järvenoja, 2014; Rogat & Adams-Wiggins, 2014), pointing out that the role of regulatory processes is critical for a quality of students' engagement collaborative learning settings (Rogat & Linnenbrink-Garcia, 2011; Volet, Vauras, & Salonen, 2009).

Our theoretical definition of regulated learning in CSCL is grounded on self-regulated learning theory, especially the regulation of learning not only with respect to individual processes, but also as social and contextual processes (Hadwin, Järvelä, & Miller, 2011). We argue that to succeed, individuals in groups need skills for regulating themselves (SRL; self-regulated learning), each other (CoRL; co-regulated learning), and together (SSRL; socially shared regulation of learning). Regrettably, many learners lack regulatory skills and struggle to develop them when they work on complex collaborative tasks (Winne, Hadwin, & Perry, 2013). Left on their own, learners often fail to interact productively in groups. For that reason increasing amounts of effort has invested to harness CSCL environments to guide and support regulation and not just knowledge construction (Järvelä & Hadwin, 2013).

In this paper we review our conceptual progress in (S)SRL research with accompanying CSCL regulation tools and empirical data examples. In our research we have been working on empirical studies in reallife learning situations to trace regulated learning in collaborative groups. Our aim has been a) to understand the sequential and contextual aspects of regulated learning (Malmberg, Järvenoja, & Järvelä, 2013), b) to focus on the individual and group level shared regulatory activities (Järvelä, Malmberg & Koivuniemi, 2014) with the help of regulation tools data (Järvenoja, Volet, & Järvelä, 2012), and c) and working for developing technological tools to prompting regulation of collaborative learning (Järvelä et al., 2014).

Our aim has been to capture individual SRL activities as a part of socially shared group level regulation. For that we have tailored and modified technological tools to prompt awareness and externalization of socially shared regulation of learning (AIRE and RADAR) in an individual and group level on-line collaboration S-REG tool extends our previous work by providing targeted support for (S)SRL based on the challenge the groups have identified. Each of these regulation tools prompt students to negotiate and reflect the key SRL processes such as goals, plans and strategies (See Järvelä, Kirschner, Panadero, Malmberg, Phielix, Jaspers, Koivuniemi, & Järvenoja, 2014). Socially shared regulation of learning targets to (meta)cognitive, motivational and emotional processes. Regulation tools make the targets of the individual and social shared regulation visible for the group members and increase possibilities to develop socially shared regulation strategies. Also, these tools offer a new way to achieve data "on-the-fly" processes of socially shared regulation which are not available in other means (Molenaar & Järvelä, 2014).

It is concluded that understanding socially shared regulation of learning often demands understanding the learning context including those situational affordances that provide opportunities for the SSRL and the evolution of social and regulatory processes over time—this is why implementing sequential and temporal aspects in the data analysis is required. Using various technologies for prompting regulatory processes as well collecting data of them can be a new avenue in SRL research and theory building also for CSCL.

Should the script theory of guidance become more social?

Ingo Kollar, Karsten Stegmann, and Frank Fischer

Based on schema-theoretical and socio-cultural assumptions, the Script Theory of Guidance (SToG; Fischer, Kollar, Stegmann, & Wecker, 2013) provides a useful framework to explain how observable collaboration processes within a small group of learners collaborating in a CSCL environment are shaped by learners' internal collaboration scripts (i.e., memory structures that guide how an individual understands and acts in a collaborative learning situation) and external collaboration scripts (i.e., scaffolds that specify, sequence and distribute learning activities and/or roles among the members of a small group that are designed to regulate collaboration). Yet, SToG has been criticised by Kirschner and Erkens (2013) for being too focused on the individual learner and the interplay of his/her internal collaboration script with a given external collaboration script, whereas the question how the internal collaboration scripts of the single members of a group interact with each other so far remained underspecified. This contribution addresses this criticism by suggesting two paths for a possible extension of SToG:

Including a differentiation of self-, co-, and shared regulation

The basic SToG assumption is that all members of a group engaging in CSCL come with internal collaboration scripts that shape the way individual learners understand and act during collaboration. So far, SToG mainly focuses on the self-regulation aspect of CSCL, but tends to neglect co- and shared regulation (cf. Järvelä & Hadwin, 2013). An extended SToG needs to offer answers to the question how the activity of one learner activates and regulates the internal scripts of another learner as well as the learning of the group. This leads to the question how to integrate the external regulation through external scripts and participants' individual or group-level regulation through self, co- or shared regulation.

Situating scripted CSCL in a broader socio-cultural context

The main focus of SToG so far, is to provide a basis for the design of instructional support of individual learners in CSCL. A blind spot, however, is how internal collaboration scripts become socially shared and how external collaboration scripts affect this process. An extended SToG needs to explain how internal collaboration spread within a social community and become a social practice. For future research in this context, it might be promising to identify communities with well-established discourse practices and to investigate whether and how newly introduced discourse practices (e.g., originating from an authority or from a bottom-up process within the community) are able to modify the overall discourse practice within the community. This would certainly necessitate a more long-term perspective for the investigation of discourse processes.

In conclusion, this contribution aims at extending SToG with respect to a stronger conceptualization of the social aspects of CSCL. On the one hand, we propose an extension that focuses on the interplay of the internal scripts of the participating individuals more systematically. On the other hand, we propose paths for future research on how external scripts that introduce and legitimize new social practices within small groups may modify the social practices that are established in larger communities.

Shared workspaces and multimedia for regulating learning in CSCL

Jeroen Janssen, Femke Kirschner, Anouschka van Leeuwen, Gijsbert Erkens, and Mieke Brekelmans

Introduction

Collaborative learning, either face-to-face or online supported by technology, requires students to engage in different activities. More specifically, students need to engage in activities in the content space (i.e., discussing task-related concept, problem-solving, etc.; F. Kirschner, Paas, & Kirschner, 2009) of collaboration and the relational space (i.e., maintaining a sound social space, ensuring mutual understanding) of collaboration (e.g., Barron, 2003; Janssen & Bodemer, 2013). Furthermore, activities in both spaces need to be coordinated to ensure effective and efficient collaboration (Janssen, Erkens, & Kirschner, 2011; P. Kirschner, Kirschner, &

Janssen, 2014). This is, however, not an easy task for learners. Computer-supported collaborative learning environments, therefore, often incorporate support and scaffolds that are aimed at supporting and fostering students' regulative capabilities.

Providing these tools, however, does not guarantee that students will be able to regulate their learning processes effectively (P. Kirschner & Erkens, 2013; Rummel & Spada, 2005). This contribution therefore focuses on how student regulation of collaborative learning may be supported by CSCL environments. This contribution outlines how shared workspaces and multimedia environments can be used to support learners' regulative processes. More specifically, we will focus on the concept of group awareness as an antecedent for regulative process and how group awareness tools can support this process. Finally, we examine the role of the teacher in CSCL environments and describe how teachers can contribute to students' regulation of their learning process. We also identify possibilities to support teachers when guiding and scaffolding their students in order to bolster students regulative capabilities.

Group awareness and group awareness tools

Group awareness has been identified as an important antecedent for effective collaboration (Janssen & Bodemer, 2013). Cognitive group awareness (e.g., information about group members' knowledge and expertise) and social group awareness (e.g., information about group members' contributions to the group process) affects regulation of students activities in the content and relational space of collaboration (P. Kirschner, Kreijns, Phielix, & Fransen, 2014; Kreijns, Kirschner, & Vermeulen, 2013). Group awareness may be enhanced by providing learners with group awareness tools. For example, cognitive group awareness tools may visualize information about students' knowledge regarding a topic (Sangin, Molinari, Nüssli, & Dillenbourg, 2011), whereas social group awareness tools may visualize students' levels of participation (Janssen, Erkens, Kanselaar, & Jaspers, 2007) or enhance the cohesion in the group (F. Kirschner, Slof, & de Kock, in preparation). Research has shown that both cognitive and social group awareness tools can be used by students to regulate their learning process and can enhance the effectiveness of collaboration (cf. Janssen & Bodemer, 2013).

Teacher regulation of collaborative learning

Recently, there has been a growing interest in the role of the teacher during CSCL (Van Leeuwen, Janssen, Erkens, & Brekelmans, 2013). Teachers for example tend to focus on students' cognitive activities and problems, thus sometimes neglecting the difficulties students sometimes encounter when regulating the learning processes. CSCL environments may therefore also support teachers in diagnosing students' learning problems and intervening adequately. Teachers' interventions may subsequently be used be students to regulate their learning process (Van Leeuwen, Janssen, Erkens, & Brekelmans, 2014). In conclusion, CSCL environments, and more specifically group awareness tools and supporting tools for teacher, have the potential to enhance students' regulation process.

Computer supported tools for co-regulation: supporting teachers and learners in problem based learning activities

Susanne P. Lajoie, Lila Lee, Eric Poitras, Cindy Hmelo-Silver and Peter Hogaboam

Theory and rationale

We examine the theoretical assumptions that best describe the regulatory activities that occur in an on-line problem based learning (PBL) environment between medical students and their facilitators who help regulate learning. We start with the guiding framework that PBL is a co-regulatory activity, in which individuals share information, build and construct new knowledge together, but their roles are not totally interdependent. Members acts in their own self-regulating interests, but may participate in socially regulating each other's learning (Volet, Vauras & Salonen, 2009). Co-regulation requires everyone work together to ease the cognitive demands of the task by sharing the metacognitive demands of monitoring, evaluating and regulating task processes (Hadwin & Oshige, 2011; Lajoie & Lu, 2012).

What is regulated

We explore the role of regulatory processes in a synchronous CSCL designed to support medical students in an international problem based learning environment. The task knowledge involves identifying goals, plans and strategies appropriate for communicating bad news to a patient. Facilitators use a medical acronym, SPIKES (setting, perception, information, knowledge, empathy and strategies and summary) to guide the learning

activity. We examine co-regulation by looking at discourse to examine the role of the facilitators in influencing the metacognitive, co-regulatory and social emotional activities.

Results

A mixed methods approach was used to analyze the group discourse from 2 PBL sessions. The group consists of 4 medical students (2 from Canada, 2 from Hong Kong, 2 medical facilitators (1 from Canada, 1 from Hong Kong) and an expert facilitator from the US. Metacognitive activities were coded using a modified version of Meijer et al. (2006) codes for orientation, planning, executing, monitoring, evaluation, elaboration. Coregulation was coded for those that facilitate (activate, confirm) and inhibit (slow, change, stop) group understanding (Iiskala et al., 2011; Hadwin & Oshige, 2011. Social emotional interactions were coded for positive elements (affective, interactive and cohesive elements (Garrison, Anderson & Archer, 2000) as well as negative factors (Rogat & Linnenbrink-Garcia, 2011).

Qualitative analyses revealed the type of regulatory interactions experienced in the PBL. Co-occurring events within the discourse were explored using sequential pattern mining to examine the inter- and intrarelationships between metacognitive activities, co-regulatory episodes and socio-emotional interactions. A strong connection was found between co-regulatory actions that activate discussion and metacognitive acts of planning. The co-regulatory activity of "activate" accounts for 82% of the variance leading to the socialemotional constructs of "contributing to on-going discussion" either moving a discussion forward by showing acceptance of other's ideas or providing additional information. The role of the facilitator is essential in activating learners to pursue their goals. There is a strong inter-relationship (92%) amongst metacognitive activities and socio-emotional interactions with respect to evaluation and interactive social presence, respectively. This result supports research by Järvelä and Hadwin (2013) who show that those who actively participate, discuss and negotiate their views help the overall group coordinate and regulate actions metacognitively.

Adaptive adjustments in the PBL group's thinking was based on continuous metacognitive monitoring and control related to that learning task which can lead to better decisions regarding when, how, and what to regulate (cf. Azevedo et al 2010). The connection between co-regulation and social emotional constructs has implications for instruction. Facilitators can help develop a shared task understanding through simple acts of activating new constructs in line with previous directions introduced earlier.

Future research about regulation in CSCL: More research is needed on the actual content of collaborations and how elements of that content assist in the regulation of learning. Our data reveal some predictability as to the timing and type of facilitator inputs that activate students to peruse goals. The confirmation of the critical role of the facilitator in small group PBL designs can lead to studies that examine coregulation in a larger-scale PBL course. We are designing CSCL tools that will assist facilitators to productively regulate collaborative engagement by providing real-time analysis of student generated content that can notify instructors of key events through a visual dashboard. Analysis will be similar to the first iteration of this research, looking for relationships between the content of dialogue and co-regulatory activity.

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Research Trends on Design and Computational Aspects of CSCL Environments

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Abstract: This invited symposium aims to provide an overview of the research trends, most important issues, and eventual solutions regarding the design and computational aspects of CSCL environments. Senior members of the CSCL community provide a critical vision of complementary, albeit overlapping, facets of CSCL environments, adopting primarily a technological point of view. These facets include, among others, architectures of platforms and tools, learning analytics, mobile and ubiquitous scenarios, as well as human computer interaction and tangibles. Cross cutting issues are discussed throughout the aforementioned facets, including how to provide both sustainability and innovation of CSCL environments, or how to achieve an integrated view of computational and pedagogical aspects.

Keywords: subject matter, teachers, technology, student learning, design, computational aspects

Introduction and overview of main issues in design and computational aspects of CSCL environments

A large number of environments, consisting of digital and physical tools, have been proposed in the last decades in order to support different scenarios of collaborative learning. Although most of these computational environments have been designed within the frame of funded research projects, some have made the transition to practice and have achieved a certain impact in real-world contexts. On the other hand, the CSCL field suffers from divisions along the classical disciplinary boundaries, which are especially relevant in the case of Learning Sciences and Technology Enhanced Learning (TEL). Even though the CSCL paradigm is inherently multidisciplinary (Koschmann, 1996), technology-related research has either been considered as the main driving force due to global technology innovations, or as a simple instrument in order to serve learning-oriented research, without specific objectives on its own.

This symposium aims to provide a critical overview and analysis of the research trends and directions, as well as of the most relevant issues regarding design and computational aspects of CSCL environments. Even though a technology-oriented perspective is adopted, special attention is paid in order to show the inter-related aspects of a multidisciplinary (or even trans-disciplinary) research beyond the strict boundaries of technology and pedagogy-oriented research. Additionally, it discusses critically the view according to which the design work is normally aimed at producing something brand new (on a 'greenfield' site) (Goodyear & Dimitriadis, 2013), under the lenses of adoption, sustainability and innovation for non-greenfield sites.

Such a critical analysis is especially relevant due to the rapidly changing landscape, which asks for a renewed view of the critical issues on which the CSCL research community might focus. Teachers, students and other stakeholders have been facing increasingly complex technology-enhanced learning ecosystems; interacting with the environment components through new multimodal and multi-sensory interfaces; and moving beyond the limits of pure formal classroom, online or blended activities, towards collaborative setups of mobile, ubiquitous and seamless learning across contexts. Furthermore, data derived from human-to-human and human-computer interactions can provide valuable analytics that may enhance regulation, scaffolding or other relevant functions of collaborative learning activities. CSCL environments should therefore provide support to the aforementioned stakeholders, in designing, carrying out and evaluating learning tasks within the most adequate physical and social architectures, allowing learners' co-configuration, according to which group members reshape or rearrange the learning environment, overriding the designer's intentions (Carvalho & Goodyear, 2014). The Ecology of Resources Approach (Luckin, 2010) may be employed, as a relevant learner-centred theoretical framework for the use of technology to scaffold learning, and therefore understand better the

underlying trends and issues. While some of the above analysis could be valuable for the overall field of Learning Sciences, CSCL presents specific challenges due to the complex social architectures that are inherent to this paradigm.

The symposium starts with a presentation by Dimitriadis of the design for learning and corresponding architectural facets in the context of the evolving technology-enhanced ecosystems, while Hoppe and Harrer provide an overview of the emerging role of Learning Analytics (LA), especially in relation to existing fields of Educational Data Mining (EDM), Interaction Analysis (IA), Intelligent Tutoring Systems (ITS), and Social Network Analysis (SNA). Looi and Wong provide an overview of design issues in mobile, ubiquitous and seamless collaborative environments, while Rogers introduces the main challenges related to the intersection of Human-Computer Interaction (HCI) and CSCL, and the role of new devices, such as tangibles or multi-touch tabletops in the changing environments of physical or hybrid classrooms. Finally, Rosé offers a critical discussion of the previous presentations towards a synthesis of the most important cross cutting issues and potential solutions.

Architectural and design for learning facets of CSCL environments

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Computational systems for collaborative learning are of different flavors, depending on their granularity and role within the educational ecosystems. The majority of those systems correspond to isolated ad-hoc designed tools, which support a specific function, as e.g. the Belvedere tool regarding argumentation. A major step forward was taken when research teams developed and proposed environments integrating various tools, in order to support several phases of the collaboration cycle (Soller, Martínez-Monés, Jermann & Muehlenbrock, 2005), as e.g. the SCY environment for science inquiry collaborative learning. However, even such integrated environments suffer from the problem of isolated islands in the classroom ecosystem, in which teachers and learners may use third-party software tools and services, as well as multiple devices. Interoperability problems have emerged, especially with respect to smooth and seamless transitions through time, when new tools are to be used in a CSCL environment. Furthermore, critical data and tools, such as those related to interaction analysis, cannot be easily adapted, connected with the learning tools, and embedded in the CSCL environments (Martínez-Monés, Harrer and Dimitriadis, 2011).

A new generation of systems have been proposed during the last decade, which adopt a more looselycoupled service-oriented architecture, where tools can be integrated rather easily according to the design needs of teachers and learners. Such a trend has been promoted by the proposal of standards, such as IMS LTI for third-party tool integration, architectures, which aim to glue together general or ad-hoc Web 2-0 tools and Virtual Learning Environments (Alario-Hoyos, et al., 2013), or even general-purpose architectures (e.g. Tuple Spaces) and messaging systems (e.g. XMPP) which have shown to be effective and scalable, paving the path towards open CSCL architectures (Vogel, Kurti, Milrad, Johansson & Müller, 2014).

The aforementioned architectural facets are intimately related to the sustainable adoption of innovative services, components and tools, since they assume the need to address the increasing role of heterogeneity and legacy in CSCL ecosystems. An interesting example of a recent architecture refers to the integration of a learning analytics workbench and other CSCL or even broader platforms in a flexible way (Göhnert, Ziebarth, Malzahn & Hoppe, 2014).

Several elements can be designed according to the aforementioned framework of design for learning proposed by Carvahlo and Goodyear (2014). Physical (including also spaces, furniture, and tangibles, besides digital artifacts) and social architectures (at the individual, group, global class or even community levels) complement the tasks to be carried out, as they are co-configured by the students in an evolving learning ecology. The apparent complexity of the resulting physical and virtual classroom has led to the need to design for classroom orchestration (Dillenbourg, 2013), which could cover the goals of configuration, real-time management, reflection and re-design. An important issue regarding orchestration refers to the ways of reducing the orchestration load, by means of a balanced contribution of teachers, learners and software agents (Sharples, 2013), while the design of "orchestable" technologies (Tchounikine, 2013) can be an essential factor in order to build effective CSCL environments.

Finally, design of the social architecture and learning tasks has been thoroughly studied in the CSCL field, especially in the form of scripts (Fischer, Kollar, Stegmann & Wecker, 2013), which aim to scaffold the learning process. However, the effective design of scripts in terms of granularity (micro and macro), adaptation and fading still constitute a major challenge. On the other hand, there is still a lot of debate on whether scripts should be designed by researchers-experts and fine-tuned by teachers, by teachers as designers, or even by students in a context of self-regulated learning. Computational support for such a design can be provided

through authoring tools, which should fit the needs of the designers (Prieto, Tchounikine, Asensio-Pérez, Sobreira & Dimitriadis, 2014), while tools can even support deployment in target learning environments and creation of appropriate learning spaces.

Based on the above analysis, we see the following challenges for future research regarding architectures and support of design of learning in CSCL:

- Further study and implementation of computational architectures, which can support the evolving and heterogeneous ecosystem of CSCL environments.
- Formulation of solid design principles to guide orchestration of effective CSCL classrooms, towards a sustainable adoption of innovative pedagogies and technologies.
- Provision of scripting mechanisms, which may reduce the orchestration load, as well as tools, which may support the associated stakeholders in authoring and deploying appropriate scripted learning spaces.

Learning analytics in CSCL

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Learning Analytics (LA) has recently been established as a new field of research focusing on the "measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (LAK 2011). Following Ferguson and Shum (2012), LA aims at supporting various stakeholders in that it is "[...] directed toward providing educators, learners, and decision makers with actionable insight to classroom and course level activities". In using computational methods to analyze and interpret data originating from learning and teaching activities, LA is to some extent similar to "Educational Data Mining" or EDM (Baker & Yacef, 2009). Yet, there is one important difference: Typically, EDM uses the analysis for the optimization of system functionality in intelligent learning environments, whereas LA aims primarily at providing information for human interpretation.

The analysis of interactions has been a major research line in CSCL from the very beginning. Initially, manual coding of video observations and dialogue transcripts have been prevalent, but quickly also computational automated approaches have been developed. Among these early approaches are the computation of collaboration factors (Avouris, Margaritis & Komis, 2004) and the multi-team research activities on interaction analysis within the Kaleidoscope network of excellence (Harrer, Martinez-Monés & Dimitracopoulou, 2009). Most of these approaches have been used to conduct basic empirical research on collaborative activities and thus did not result directly in actionable analytic results and ensuing interventions. However, there are examples that can be seen as predecessors what is now called Learning Analytics. E.g., in the Argunaut project (De Groot et al., 2007; McLaren et al., 2007) moderators were provided with analysis results of argumentative classroom discussions via a so-called "moderator's cockpit" that also enabled the initiation of certain feedback actions. This approach combined dashboard-style supervision support with the enabling of direct action on the part of instructors.

In our understanding of LA, the characteristic elements are the computational generation of analytic results and, at some stage, the usage of these results by human stakeholders to improve the learning process. This allows a distinction from classical Intelligent Tutoring Systems (ITS) in which the intervention is automated and mainly used for content and task solution feedback on the one hand, and from pure empirical research work where the purpose of analysis is investigating a research question without direct interventions. The "loop" closed by the human stakeholder using the results can be both indirect and asynchronous, such as a teacher re-designing a course for the next year based on analytics results, or direct and synchronous to support self-regulation activities of students, which might use analysis-based feedback to coordinate their activities with peers, set new goals etc. For the learners the immediate applicability of presented results / interventions is more important and requires thus a deeper level of LA into the learning process (Wise, 2014).

Among the computational methods used in LA, Social Network Analysis or SNA (Wasserman & Faust, 1994) is particularly suited to analyze the internal social structure and roles in learning or knowledge building communities (cf. Haythornthwaite, 2003). In addition to social interaction, knowledge building and productive learning processes also involve the creation of knowledge artefacts. The relation between the actor (or author) and the artefacts created ("learner-generated content") defines another important analysis perspective in CSCL. Hoppe et al. (2005) have used such artefacts in a learning community to instigate ad-hoc collaboration based on common interest. By adapting methods from science analytics ("scientometrics") also the evolution of

knowledge artefacts in a learning community can be assessed in such a way as to identify the main contributions and corresponding actors (Halatchliyski et al., 2012).

Based on this view of existing work, we see the following challenges for future research on LA in CSCL:

- Further development of multi-method approaches involving artefacts analysis (e.g. based on linguistic methods) with interaction analysis and (social) network modeling.
- "Informed methods" exploiting LA results to improve the supervision, support, and management of learning communities, a specific subtopic being support for small group formation in online courses with large number of primarily anonymous participants.
- Specific representation and visualization of analysis results to support various stakeholders, especially when LA is used for immediate self-regulation feedback or supervision support.

Current trends and directions in design of mobile CSCL

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Mobile learning offers the premises that learners are mobile, mobile technologies are ubiquitous and ready-athand, and learners can learn and collaborate in context (Looi at el., 2010). The unique characteristic of "mobility" offers opportunities for learners to share and construct knowledge readily in different settings and modes. Current mCSCL pedagogical design and practices can be categorized into three main types: in-class, out-of-class, and mobile CSCL that bridges both in-class and out-of-class activities (Looi, Wong & Song, 2011). In-class mobile CSCL typically augments the conventional face-to-face collaboration of physical classrooms with networked communication through devices (Nussbaum et al. 2009, Boticki, Wong & Looi, 2013). Out-ofclass mobile CSCL supports situated, experiential, social and inquiry views of learning in situ, typically in field trips and outdoor activities such as Ambient Wood (Rogers & Price, 2009) and LET'S GO! (Maldonado & Pea, 2010). Mobile CSCL can support seamless learning in bridging both in-class and out-of-class activities (Looi et al., 2010).

The affordances and constraints of mobile technologies influence the possibilities for collaboration. A small screen size does not have to be a barrier to collaborative work, in that they afford multiple users viewing their displays. Devices can be used for short bursts of time (e.g., entering and comparing data, looking up and reviewing information, brief communication and sharing of artifacts with peers and remote people) to support foregrounded physical activities in-situ (Rogers, Connelly, Hazlewood & Tedesco, 2010). The additional means of communication such as verbal interactions among collaborating learners who are physically close to each other may serve as crucial supplements to the technology-mediated communication, and become indispensable components of the socio-cognitive processes.

A "division of labor" strategy can be adopted, with each learner keeping one smart-phone and one laptop at hand to handle the needs of various formal and informal, planned and incidental learning tasks. The small size and light weight of smart-phones make them the perfect tool for learners to perform quick and rapid learning tasks on the move, including scripted or spontaneous communication or collaboration. When learners have the chance to sit down (either during a field trip, on public transport, in the library, in the park, or at home), the bigger screen device will compensate for the limitations of the smartphones by enabling more "complex" learning and knowledge building tasks (So, Seow and Looi (2008), Thompson and Stewart (2007), and Wong, Chin, Tan and Liu (2010)).

A productive and realistic approach is for mobile CSCL activities to be situated in a broader curricular or learning flow system in which mobile CSCL supports in-context interaction and context delivery and creation, as well as time and space for personalized and social learning.

From a research point of view, for mobile CSCL studies that bridge formal and informal contexts, new methodological challenges emerge such as the need for data collection methods that can capture mobile CSCL processes and outcomes in continually moving and re-constructed contexts. Learners may carry and use their mobile devices as their personalized devices to do a range of activities, only some of which may be relevant for the analysis of CSCL interactions. The distributed and sparse nature of interactions through and over mobile devices poses a challenge for tracing the uptake of ideas and idea development processes.

Based on our views of existing work, we see the following challenges for future research on mobile CSCL:

Issues of orchestration supported by technical architectures to support learning scenarios/flows across different learning spaces and devices.

- Synergy between contextualization/personalization of learning with mobile and ubiquitous technologies, and the affordances for collaboration. Mobile technologies afford individual personalized learning, and how does that contribute to CSCL?
- Advances in methodological collection and analyses of data coming from multiple learning spaces and devices, including the data that arose from non-technological means of communication such as verbal interactions. There will be enormous challenges for multi-level and multi-dimensional analysis of different interrelated sources of data in reconstructing the learners' collaboration process.

Collaborative learning, orchestration, and new ways of distributing technologies in the classroom

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Learning theories such as constructivism (Piaget & Inhelder, 1969) and communities of practice (Lave & Wenger, 1991) have argued that learning should take place through active inquiry, exploration and design (Papert & Harel, 1991) and social interaction with peers (Duffy & Jonassen, 1992) These views of learning have inspired a number of studies that have tried to transform the classroom into participatory learning spaces, where students collaborate through a network of interoperable computing devices of various shapes and sizes. For example, Moher's RoomQuake (Moher, Hussain, Halter & Kilb, 2005) was designed to enable a whole class to observe and study a simulated earthquake, using both low-tech and high-tech materials, such as shared displays, a subwoofer and some Styrofoam balls and strings. This and related simulations replicate natural phenomena at the scale of a classroom, with the main goal to help students develop scientific thinking as a community of practice. Input devices and sensing technologies are configured to enable students to interact with a simulation through decision-making and role-play. An example, is the spread of a virus using wireless, wearable Thinking Tags (Colella, 2000). Another example is Kreitmayer et al's (Kreitmayer, Rogers, Laney & Peake, 2012) 4Decades simulation of climate policy-making where participants shared a network of tablets and wall displays to debate and reflect on global spending decisions. Their studies showed how students greatly benefited from this form of distributed learning activity. However, to what extent such applications can be integrated into everyday classroom settings depends on a number of factors, including the availability of the required hardware and software, logistics, maintainability, compatibility with existing infrastructure and preparation time. Moreover, teachers need to be able to learn how to orchestrate those collective activities, as this is not straightforward. A question for Human Computer Interaction and Computer Support to Collaboration SC, therefore, is to determine how to achieve this; where the teacher can easily set up, manage and orchestrate the technology, the software and the classroom activity.

Dillenbourg and Jermann (2010) have described how teachers orchestrate an activity by coping with technical, pedagogical and social constraints. Their framework has influenced a number of studies on teaching with networks of multiple tabletops and wall displays (Kharrufa, Balaam, Heslop, Leat, Dolan & Olivier, 2012; Martinez-Maldonado, Kay & Yacef, 2012). Studies of multi-tablet (Kreitmayer, Rogers, Lane & Peake, 2012) and multi-tabletop (Mercier, Higgins, Burd & McNaughton, 2012) applications have suggested that directing students' attention away from the tabletop interaction at arbitrary moments may require explicit intervention, such as remotely 'locking' the tabletops, i.e. temporarily disabling their touch responsiveness. Future research needs to determine whether and how effective whole classroom orchestration can be achieved with a more lightweight, set-up that can be easily set-up in everyday teaching practice using distributed technologies, and which exploits the new technologies promised by the Internet of Things agenda (Kreitmayer, Rogers, Laney & Peake, 2013).

Synthesis and discussion

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The field of CSCL not surprisingly values intensive collaboration, and with the vision of collaboration as a value comes the dream of deep interdisciplinarity. Recent reflections on the field of CSCL have pointed to the issue that while CSCL work draws substantially from the disciplines of Psychology, Education, Design, Computer Science, and other fields, its representation from Design and Computer Science are disproportionately small. This symposium seeks to pave the way for achieving greater balance by highlighting three thriving areas of active research stemming primarily from the discipline of Computer Science, but with great value and potential impact within the field of CSCL. The hope is that in highlighting the contributions made within these

areas, as well as the active current directions, the discussion at the conference will spark or renew interdisciplinary collaborations.

As a step in this direction, let us reflect on how to afford an intensively interdisciplinary discourse within these areas using as an example, the Multivocality paradigm that has been investigated in the analysis of collaborative learning interactions (Suthers, Lund, Rosé, Teplovs & Law, 2013). In that paradigm, a diverse assortment of researchers with their own theoretical and methodological commitments each analyze a data set from their own perspective. What provides a boundary object to facilitate exchange is a common question. The researchers each do their own work, but then come together to share their work products, discuss, reflect, and then iterate. The common data and shared question provide just enough focus to reveal the interesting differences in perspective in order to facilitate intensive exchange.

The second contribution relates to learning analytics and provides the closest parallel with the Multivocality example. Within this sphere it is difficult for those with sparse exposure to computational modeling technologies to understand what can be modeled, and what representation of data would enable meaningful modeling, while the modelers might understand these things in detail, but might have less insight into what are interesting questions to ask, what are reasonable assumptions to make, and what the resulting models might communicate. However, in joining forces to analyze the same data first individually, and then coming together to compare and discuss, a more active and targeted exchange between subcommunities might be achieved that could lead to plans for joint modeling work that could overcome the limitations that either subcommunity would face on their own.

But what about the other contributions? The first contribution to the symposium highlights important directions in architectural standards for collaborative system architectures. It is challenging to appreciate the importance and subtlety behind the design and usage of such standards until one is faced with the task of implementing an experimental intervention that must conform to these requirements. Ideally the discourse on standards for protocols like this should enlist the deep involvement of researchers whose work will depend on implemented interventions for their studies to comply with them, although sustaining that interdisciplinary exchange is tricky for practical reasons. The final two contributions highlight CSCL in complementary distribution, in one case mobile CSCL, where learners may be on the go, and in the other CSCL within the classroom. Nevertheless, from a behavioral perspective there are cross cutting concerns related to learner autonomy and context switching as well as joint attention and shared experiences. From a technical perspective, there are reasons why it makes sense to consider these separate areas. However, it is interesting to think about the ways in which discussion of differences as well as similarities as seen from the technical and from the behavioral standpoint might increase mutual understanding. Common understanding would enable more effective implementation as well as greater awareness of what can be done and what would be interesting to ask. Similar to the situation with standards, from an end user perspective it might be easy to focus on limitations of the state-of-the art, whereas a more productive engagement would produce consensus on priorities and shared agendas. In these contexts, what would be analogous to common data and a shared question? Perhaps what is needed are challenge scenarios with realistic problems that occur in interaction or learning, where computer scientists and behavioral researchers can work together to flesh out visions for environments in which related scenarios can play out, and where the problems of interest can be observed and studied.

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Learning Analytics of and in Meditational Processes of Collaborative Learning

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Abstract: This panel will illustrate and discuss the potential of Learning Analytics, viz. computationally supported collection and analysis of data about learners and their settings, to analytically uncover mediational processes in CSCL and possibly participate itself as a mediator. The focus on meditational processes takes the conference theme of the "material conditions" of learning broadly to include cultural, digital and physical "material". The panel illustrates the relevance of Learning Analytics for CSCL with applications ranging from dyads and small group interaction to meditational processes in communities.

Keywords: learning analytics, meditational means, network analysis, epistemic, computational, multimedia, multimodal

Introduction

Learning Analytics (LA) has been defined as "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs" (Learning Analytics and Knowledge 2011 web site). There has been an emphasis on organizational needs, particularly in higher education; on "big data", particularly in conjunction with the recent popularity of xMOOCs; and on how to leverage the explosion of social and Web 2.0 media for learning objectives. Thus, learning analytics is motivated in part by "rapidly expanding forms of social, cognitive and technical mediation" (CSCL 2014 conference theme). However, learning analytics also includes work that deals with "small data" and looks closely at interaction in other settings. The third conference called for a "productive multivocality" between the various strands in the LA community (Learning Analytics and Knowledge 2013 chairs' introduction).

This panel does not attempt to be representative of LA as a field, but rather brings to our attention specific work of interest to CSCL. Inspired by the conference theme of the "material conditions of learning", and taking "material" broadly to include conceptual and digital artifacts as well as physical ones, this panel focuses on *learning analytics of the mediational means of learning in social settings* (i.e., CSCL broadly construed). Examples of mediational means from the panelists' work include discussion messages as conceptual and interactional resources; gestures and gaze in relation to one's physical setting; discourse elements evidencing the skills, knowledge, identities, values, and epistemologies of a community of practice; how digital media participate in forming communities in a large online network; and the evolution of ideas and domain concepts over time in communities. When we ask how actors and mediational means factor into learning in interaction, networks (particularly multimodal networks) provide natural models; hence we see several networked based approaches on this panel. However, when analyzing the mediated interaction of dyads and small groups, other methods tracing interaction over time, space, modalities and media are also useful, and are represented on the panel. Panelists are asked to use their work to address the questions: What potential does learning analytics have to either *uncover* or *participate in* mediational processes in CSCL? What are its limitations?

Our discussant is George Siemens, a founder of the Learning Analytics and Knowledge conference series and its associated Society for Learning Analytics, and hence the world's foremost promoter of learning analytics, but also a person who is experientially grounded in the challenges of applying learning analytics in his online courses. Siemens is the originator of connectivism, a theory of learning as the formation of networks of connections at levels ranging from the brain to the socio-cultural. He also originated MOOCs as connectivist or "cMOOCs", based on his strongly social vision of learning, to be distinguished from the current trend in which large numbers of individuals work through courseware in "xMOOCs". He has indicated that he will ask panelists to address the gap between learning analytics theory and practice. Brief statements from the panelists are below.

Alyssa Wise, Simon Fraser University

While advances in the availability of data and methods for processing it present exciting opportunities to provide real-time feedback to students on their collaborative processes, translating a CSCL research program into learning analytics is far from trivial. An additional knowledge base is needed to leverage CSCL methods and models to be useful and effective in this context. Specifically, there are four core issues to address: (1) reconciliation of the inherent group orientation of CSCL with the fundamentally individual orientation of Learning Analytics; (2) how to interpret data traces of collaborative learning processes that are in progress rather than completed and may be part of a larger trajectory of learning to collaborate; (3) recognition of students and teachers (rather than researchers) as the active agents who will receive, interpret and make decisions based on the results of the analyses; and (4) the existence of the analytics themselves as a change in the material conditions of learning that mediate interactions between learners and their learning environment, their instructor and their peers. This perspective emerged out a CSCL research program investigating how students attend to the messages of others in asynchronous online discussions (The E-Listening Project). One of the material conditions of an online discussion is the products of others: messages mediate learner interactions with both the conceptual content of the discussion and each other. Thus how students engage with existing posts is an important, though often overlooked, element of participation in a discussion. Our research tracks how students attend to others' posts and presents analytics that students and instructors use to reflect on their discussion participation. Some analytics were embedded in the learning environment to provide students with real-time information on their activity in-progress; and others were presented to students in a separate digital space for reflection. In both cases the creation of the analytics represents a change in the material conditions of learning that mediates how learners interact with the discussions, each other, and in some cases, the instructor.

Bertrand Schneider, Stanford University

Nowadays, virtually all of educational outcomes in schools are measured by a unique product (a test, a portfolio or a project), while measuring the process of learning is mostly neglected. New sensing devices are now affordable and scalable, allowing us to 1) capture fine-grained information to perform formative assessment, and 2) feed this data back to students to support small group learning. In my own research, I have been using multimodal learning analytics (MMLA) techniques to study and support collaborative learning. More specifically, I have been designing computational measures of group synchronization by applying Natural Language Processing techniques to students' transcripts, unsupervised machine learning algorithms to students' gestures (collected from a Kinect sensor) and cross-recurrence quantification to students' gaze (collected from a dual eve-tracking setup). I have found joint visual attention and discourse synchronization to be strong predictors of collaborative learning, while physical synchronization did not seem to be associated with productive interactions among dyads of students. Additionally, a promise of MMLA is the ability to design awareness tools to redirect this multi-modal stream of data back to learners, so that they can make better and more informed meta-cognitive choices when discovering new concepts. Following this line of work, I have found real time mutual gaze perception (i.e., students' ability to see the gaze of their partner in real time) to positively influence students' collaborative learning; additional findings suggest that visualizing collaborative eye-tracking data as networks (where the nodes of the graph represent joint fixations and edges represent saccades of a group) can provide researchers with strong predictors for different facets of a productive collaboration.

David Shaffer, University of Wisconsin-Madison

Epistemic network analysis (ENA) looks at computer supported collaborative learning as an occasion to assess performance in context by modeling the uptake and use of mediational means during collaborative problem solving. Three characteristics of ENA exemplify critical issues to this panel and to modeling the uptake and use of mediational means in collaborative learning. First, ENA is theory based. Mediational means do not exist in isolation. Epistemic frame theory, on which ENA is based, suggests that becoming part of a community of practice can be modeled by exploring the cognitive connections that individuals make among meditational means of a particular practice: the collection of skills, knowledge, values, identity, and epistemology that forms the epistemic frame of the community. This leads to a second characteristic of ENA: it is network based. ENA extends network science to develop tools for analysis and visualization that are specifically designed to investigate how connections among mediational means are formed and leveraged during collaborative learning. ENA collects longitudinal data in situ that document the development of and linkages among mediational means. These data are represented in a dynamic network model that quantifies changes in the strength and composition of an individual's epistemic frame over time. Specifically, ENA looks at the things an individual says or does for evidence of one or more mediational means from a community of practice. The association

structure of the discourse is modeled by creating an adjacency matrix of mediational means based on their cooccurrence in discourse over time. Finally, while ENA is a computational technique and well-suited to the kind of data generated in computer-supported learning environments, it is equally suited to analysis of a wide range of qualitative data on collaboration.

Dan Suthers, University of Hawai'i

Work at the University of Hawai'i addresses the meditational means of learning at multiple granularities, and includes a line of work explicitly intended to bridge levels. Here we focus on our study of mediated communities in Tapped In, a formerly large and active online network of educators cultivated by Mark Schlager, Judith Fusco and Patricia Schank. Participants and organizers could choose between various digital media, including synchronous chats and asynchronous discussions and file sharing. Inspired by Licoppe & Smoreda's observation that the nature of interpersonal relationships is reflected and reaffirmed in the choice of media through which people interact, we ask how the nature of communities are reflected in their choice of media. Inspired by Latour, we treat media objects as "actants" that participate along with human actors in assembling social entities. The Tapped In network is modeled as a bipartite (actors and media) multimodal (chats, discussions and files) directed (read, write) weighted (number of events) graph. Then, a "community detection" algorithm is applied to the graph to find cohesive subgraphs that evidence collections of people and the media through which they interact. Inspecting the attributes of the actors and the nature of the media included in each cohesive subgraph, we can identify meaningful social entities (e.g., an asynchronous communities of practice mentoring program run by a large school district, or a sheepherder in Australia running a small English as Second Language chat group). The fact that graph clusters found through automated means were interpretable as meaningful by Tapped In developers illustrates the potential of network modeling methods to identify social phenomena that are the settings of learning interactions. Other techniques being refined in our laboratory are then applied to understand the nature of interaction in particular sessions and the roles of community members in these sessions.

Ulrich Hoppe, University of Duisburg-Essen

Learning Analytics features an inherent interest in computational methods of analysis and algorithms. This is not necessarily related to big data and corresponding algorithms and architectures. The "analytic" aspect is not just about empirical analyses in technology-rich settings, it actually also calls for non-trivial computational approaches as part of the analysis. This makes Learning Analytics a rewarding area for computer scientists and mathematically inspired researchers. Algorithmic approaches used in Learning Analytics include analytics of (1) content using text mining or other techniques of artefact analysis, (2) network structures including actor-actor (social) networks and also actor-artefact networks, and (3) processes using methods of sequence analysis. Of these, only actor networks directly address the social aspect of CSCL. However, sequential pattern analysis can be extended to include user-ids representing ownership and transactional patterns homogeneously without actually changing the underlying methods. As an extension of social networks, actor-artefact networks have been studied, e.g. to identify the evolution of ideas in knowledge building communities (e.g. Halatchliyski, Hecking, Göhnert & Hoppe, LAK 2013). Focusing on artefacts, the computational analysis of learner-generated content can reveal learners' understanding of domain concepts and especially misconceptions using text-mining methods (Daems, Erkens, Malzahn & Hoppe, J. Computers in Education 2014). Regarding temporal patterns in learners' action logs, Bannert, Reimann, & Sonnenberg (Metacognition and Learning, 2014) have used Process Mining, a computational technique with roots in theoretical computer science. It is both a challenge and an opportunity for CSCL to give more importance to such computational methods of analysis.

Papers

"That's What Everyone Else Is Saying...": Collaborative Reflection-in-Action during Creative Activities

Michael P. Downton, St. John's University, downtonm@stjohns.edu

Abstract: With the progression of more user-friendly music production software packages (i.e., Apple's GarageBand) and the importance of social media, learners are engaging with music without having any formal education on important musical concepts. It has been suggested that novice music learners should start with what they know how to intuitively do already, which will allow them to move to more sophisticated musical concepts (e.g., notation, intervals). However, music production is becoming more a group project than a solitary one in which everyone in a group has a voice. A fourth grade classroom (N = 36) engaged in a music curriculum using the learning software Impromptu. Findings suggest that when students are able to reflect-in-action, their reflections become building blocks for others in the group to use and add to their knowledge base.

Keywords: music, intuitions, social negotiation

Introduction

Since the release of "How Popular Musicians Learn" (Green,2002), there has been a stark divide in the field of music and music education about her claims that traditional (musical) literacy (e.g., note reading, note writing, formal instrument training) through formal instruction is not the norm in the changing musical culture. More specifically, musicians are learning their craft by engaging in constructionist and sociocultural practices (e.g., playing in bands) and learning from each other (Green, 2002; Sawyer, 2008). And with the advancement of technology-based consumer music production tools, learners are able to create music with no prior musical knowledge or performance skills.

This is exemplified when looking at tools like Apple's GarageBand. Since its release in 2004, online web communities have begun to emerge that give users a place to share, critique, and collaborate with other GarageBand users. Not even 15 years ago was this possible; space was limited and the technology to create too expensive. This is a major shift in how music is both consumed and, more importantly, created. What was once perceived as a solitary act of music composing via paper and pencil is now a group activity (e.g., rock and roll band).

This provides a challenging area for CSCL and the Learning Sciences to investigate because it requires researchers to design environments that emphasize an intuitive approach to (music) learning within group settings using technological tools that are not normally used in music learning environments. It has been suggested that utilizing an intuitive approach to music learning provides a "doorway-in" (Wiggins, 2009 p. 39) into more formal musical concepts. Bamberger (1996) further suggests that if beginning music learners can start off at a mid-level structure (what they already intuitively know) this allows them to move to more sophisticated musical concepts (e.g., pitches, whole song evaluation).

The purpose of this paper is to present data guided by the question: How do fourth-grade students take up and utilize intuitive discourse during computer-aided music making activities? Fourth-grade students (N = 36) took part in a five-week music learning course using the software Impromptu (Bamberger, 2000). During the course, students worked as a whole group to compose different tunes based on the goals of the specific activity. Data includes transcribed audio from video that was taken during whole class activities. The transcribed data was coded and mapped onto the structural musical ladder (Bamberger, 1996) and further analyzed to detect when students took up and used other student's ideas in the creation of a musical composition.

Background

The National Assessment of Educational Progress (NAEP) in the Arts show students in 8th grade averaged a score of 150 out of 300 in music (Keiper, Sandene, Persky, & Kuang, 2009). Unfortunately, this low score is confounded by the fact that both time and money are being cut from most arts related programs in schools today. However, the larger issue is the way in which music educators approach the teaching and learning (e.g., the transmission model) of music. Commonly, novice learners are introduced to concepts like musical notation, rhythm, and tempo via instrument performance, dancing, and body movement exercises. If the goal in music

education is to get learners to identify, describe, and demonstrate their knowledge, then the activity of music composition aligns well with these goals.

One glaring omission from the 2008 NAEP was that youth were not given the opportunity to create their own music. And, out of all the activities that do take place in a music classroom, giving learners the opportunity to make their own songs was least valued by educators (Keiper, Sandene, Persky, & Kuang, 2009). Giving young learners the opportunity to create their own music gives teachers and researchers a more clear insight into the development and knowledge of the learner (Swainwick & Tillman, 1986). Music composition, while arguably a creative and aesthetic activity, is also an ongoing and evolving problem solving activity. The composer is constantly solving new and interesting problems that emerge in the composition process both during and after the composition has been constructed (e.g., melodies, harmonies, counterpoint, tempo, dynamics). Composing a tune previously meant putting pencil to (staff) paper and then waiting to hear the finished product. Technology has changed that and the feedback is instant. Users do not need to know about musical literacy concepts (e.g., notation, chords, intervals) in order to compose music.

Yet, Webster (2006), in his extensive review of technology's role in music learning, asserts that still little is known about the true impact of technology in music learning because 1) we do not know how technology is being integrated, 2) how much do music teachers know about the technology, and 3) there seems to be no philosophical consensus on why and how technology should be used in music learning.

Webster's (2006) assertion that there is no consensus on why and how technology should be used in music learning is one that should be addressed first. If there is no theoretical or philosophical framework for using technology to support learning, then the technology and the time in classrooms and afterschool programs is wasted. While there have been calls for a theory of technology in the music classroom, much of the discourse has been nothing more than making the technology available and reporting on how users engage with the technology (c.f., Savage, 2005; Bray, 1997; Dalgarno, 1997). This is where CSCL can play a large contributing role. Educators who are concerned with music learning must recognize that the computer and other technologies are fundamentally changing the way in which people participate and interact. The best way to understand how these technologies support learning is to incorporate already established theories of learning, design, instruction, and analysis that have technology incorporated into its framework (Webster, 2006).

Composition and constructionism

Simply giving the learner access to the technology is not sufficient. While they may create a music composition, without giving them a chance to reflect on their work, both during and after—what Schön (1983) calls reflection-in-action (during the creative process) and reflection-on-action (after the creative process to affect future decisions)—does not provide a clear lens at viewing what the learner knows. Constructionism, I argue, provides that lens.

Constructionism is the idea that learning happens when learners can construct their knowledge and this happens best when they are building (constructing) something that is personally meaningful to them (c.f. Papert, 1991; Kafai, 2006). Building on this, sociocultural constructionism (Pinkett, 2000; Peppler & Kafai, 2007; 2009) argues that both individual and community development are better understood when the artifacts are an expression of the individual and the community as a whole and our understanding of the artifacts changes because of the sociocultural nature of the activity. Unpacked further, a sociocultural constructionist model places greater emphasis on exploration and the distributed nature of knowledge that happens between teacher and student or between groups of students working together (Papert, 1993). Both the sociocultural nature of learning and interaction as well as the opportunity to reflect through discourse are central themes in the field of CSCL, but virtually non-existent in formal music education (c.f., Green, 2002).

Reflection-in-action and intuitions

Approaching music literacy (e.g., reading, writing, and performing) from an intuitive perspective provides the learner the opportunity to engage with music at a level she feels most appropriate. Intuitions have garnered some attention in the Learning Sciences over the years. Specifically the work of diSessa (1993), who promoted the idea that through our experiences in the world, we develop a "sense of mechanism" (p. 106) of how things work. This sense of mechanism is then further broken down into phenomenological primitives (p-prims) that are small pieces of knowledge that help us explain some phenomena (e.g., Ohm's P-prim). Intuitions in music have experienced greater attention through the work of Jeanne Bamberger. However, there are no musical analog's similar to p-prims. For example, there is no "rhythmic p-prim" that has been identified.

The reason for this is because of the cultural and contextual nature of music. Bamberger (1996) and others (c.f., Swainwick, 1994; Wiggins, 2009) have suggested that giving learners the opportunity to start with what they intuitively know already is key to moving to other, more sophisticated forms of musical knowledge.

Bamberger promotes the notion that novice music learners begin at a mid-level structure; that is, what they understand and then move up and down a musical ladder; recognition and use of sophisticated musical literacy concepts (1996) (see Figure 1).

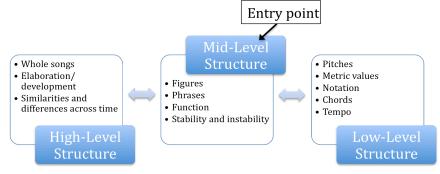


Figure 1: The Structural Musical Ladder – Adapted from Bamberger (1996, p. 45)

Through students interactions with music, especially when using the computer tool Impromptu, learners move to more detailed, or low-level, structures (e.g., notation, pitches, chords) as well as larger, or high-level structures (e.g., evaluation, developments, similarities and differences). This is because as they interact with the software and each other, their hearing of a tune, and thus their intuitions, change. To make sense of what is going on, they must deconstruct the tune to lower-level structures and/or think about higher-level structures of the tune they are composing (Bamberger, 1999). This is why it is crucial to give learners the opportunity to express what it is they know or think they know (Chi, et al, 1994). To do this, learners should be encouraged to talk while they are in the act of making something.

Reflecting both in- and on-action is, in essence, a metacognitive process in which professionals / experts can express what they know—via a demonstration, performance, or talking—within a specific domain (Schön, 1983; 1987). When a professional (e.g., an expert) engages in their domain specialty, the knowledge they use is located within the activity itself and any new knowledge gained is constructed through a reflection-in-action process. More specifically, when the feedback during an activity is, for example, surprising, this promotes a reflection-in-action. This reflection, in turn, allows for explicit knowledge to be used and new knowledge to be constructed. A component of these reflections are the professional's intuitions (Schön, 1983; 1987). I contend that intuitions and a reflection-in-action activity can help the non-professional construct new knowledge.

Methods

The research in this paper specifically addresses the impact of utilizing reflection-in and on-action approaches in computer-aided music composition activities. More specifically I ask: How do fourth-grade students take up and utilize intuitive discourse during computer-aided music making activities?

The data and subsequent analysis is drawn from two fourth-grade classroom (N = 36) working to construct musical compositions using the music learning tool Impromptu (Bamberger, 2000). The 20-hour curriculum, grounded in a constructionist framework (Papert, 1980), involved students reconstructing tunes, building rhythmic patterns to tunes, and composing their own tunes while engaged in a dialog with the practitioner and others in the class.

The tool and curriculum

The computer software Impromptu (Bamberger, 2000) was used throughout the study. Impromptu is a music learning tool that allows users to construct and manipulate tunes and rhythmic patterns using what is known as tuneblocks (see Figure 2). Users pick a tune from the library. Once the tune is selected, they are presented with an assortment of tuneblocks. These tuneblocks can be arranged in any order and repeated as many times as the user sees fit in the playroom. Users can also manipulate the tuneblock itself. For example, the user can click on the magnifying glass icon in the tuneblock editor, click on a tuneblock, and then proceed to change the pitch, duration, and/or rhythmic structure of the block.

This tool is unique, especially to this study, in two ways. First, Impromptu is not a composition tool, but a learning tool. Bamberger (2000) explicitly designed to the software to allow users to question their intuitive notions about music and thus modify or change their intuitions based on their interactions with the

musical tuneblocks. Second, and most importantly, the users begin at a mid-level structure or, as Bamberger (1996) argued, with what they already know. Studies of intuitions both within music and other domains suggest that the learner should be engaged with something familiar so that an intuition may be triggered when engaging with a problem (Bamberger, 1996; Bowers, et al., 1990; diSessa, 1993; Easen & Wilcockson, 1996; Fischbein, 1982; Laevers, 1998; Wiggins, 2009).

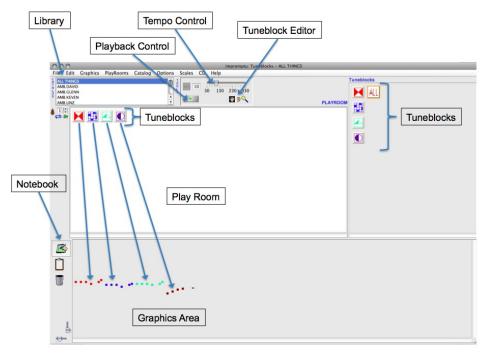


Figure 2: Impromptu screenshot with labels added

The 20-hour curriculum for this project is taken from Bamberger's (2000) college level curriculum and adapted for a fourth-grade classroom. The activities included Reconstruction, Construction, Building Meter, and the Final Project. Briefly, the Reconstruction activity involved choosing a particular tune from the Impromptu library (e.g., Hot Cross Buns) and using the given tuneblocks to put the tune back together. The Construction activity consisted of picking a pre-determined tune from the library and using the blocks to create a new composition. The tuneblocks for this activity were rhythmically and melodically balanced (e.g., tonal) and did not require the student to alter the individual tuneblock. The Building Meter activity consisted of choosing a pre-determined tune from the library is beat to the tune using the given rhythmic tuneblocks. The Final Project activity allows the students to make their own tune. This involves picking a tune from the Impromptu library that consists of blocks that are atonal (no melodic or rhythmic balance) and, should the student feel it is necessary, edit the given blocks and/or create new blocks in order to compose their music.

Data and analysis

The data are comprised of audio and video of the activities made during the composition activities. The qualitative excerpts provided were analyzed using a microdevelopment approach in which learning and development is investigated over relatively short periods of time (Granott & Parziale, 2002). Specifically, during each of the whole-class activities (Reconstruction, Construction, Building Meter, and Final), units of analysis were based on turn-taking events between practitioner and student or between student and student. These turn taking events were coded based on the Structural Musical Ladder (Bamberger, 1996) (see Table 1).

Table 1: Description of the structural musical ladder and the specific codes that apply

Structural Musical Ladder	Code	Description
High-Level Structure Overall organization of piece of music, motiv, or phrase (e.g., tuneblock). Includes style, mood, and evaluation	Style	Style refers to the genre (e.g., rock and roll) of the piece being heard or created
	Mood	Mood refers to the feeling the piece of music has on the listener
	Evaluation	Evaluation is an assessment of the piece being heard or created
	Instrumentation	Describes the instrument(s) used in the piece of music
<u>Mid-Level Structure</u> Describes the ways in which elements of the tune function within a specific context. This can include melodic contour, repetition, rhythm, tempo, tonal center, resolution (i.e., endings), antecedent/consequence, and division of beats	Repetition	Describes/notices how patterns (e.g., tuneblocks) repeat
	Rhythm	Describes rhythm of the piece and how the beats work together to form the rhythm
	Tempo	Describes the speed of the piece
	Tonal Center	Describes the overall tonality of the piece. That is, the notes in the piece compliment one another and are pleasing
	Resolution	Describes the ending of a tune or how a tune should end/resolve
	Antecedent/ Consequence	Describes a "question and answer" functionality of the music. Usually happens when one phrase ends with either a high or low note (or sequences of notes) and the subsequent phrase ends with the opposite of the preceding phrase.
	Division of Beats	Describes how the beats in the music are divided up
	Melodic Contour	Describes the relationship of the notes and how they work together in the context of what is being heard / created
Low-Level Structures A deconstruction of mid-level structures including pitches, chords, and metric values.	Pitches	Describes or demonstrates (e.g., hums) the individual notes and or sound of individual notes being uses
	Chords	Describes the use of chords (e.g., two or more notes played together) in the tune being created
	Interval – Melodic / Rhythmic	Describes or demonstrates how melodic (e.g., pitches) or rhythmic elements are divided.

Specifically I was looking for instances when students would discuss and/or put to use another student(s) suggestion and how this impacted their movement on the Structural Musical Ladder.

Findings

Due to space limitation, one excerpt from the "Final Activity" is presented. Students were told they could construct any type of tune they would like using any or all of the strategies that were employed throughout the intervention. At this point in the excerpt, the class had spent considerable time deciding on the genre or style of

music they would like to compose. The style they chose was called "techno-adventuresome" indicating that the song should be exciting—like what would be heard in the movies—but also electronic sounding. As students made suggestions, the practitioner would build the blocks and play them. Opinions were mixed on what was being constructed at this point. For this specific excerpt, the practitioner played a newly constructed beginning. When asking the class what they thought, a student—Sam—has suggested that in order for it to be "techno", it needs to be faster and the conversation develops from that point (see Table 2).

Line #	Name	Transcription	
1	Practitioner	Making it faster really didn't work	
2	Connor	It's a war song (uses hands to act like he's holding a gun) (Teacher walks in—class gets quiet)	
3	Ali	I don't like it at the beginning. Now it's like way to deep and makes you feel like you're in a weird movie and it's getting really scary. And then um, I think it should be like Sam said and more techno, like change the instrument	
4	Practitioner	How do we want to change it? Owen, go ahead?	
5	Owen	I think we should make a new block and, um, make it take littler steps and then make another block and add on to it, like from the note we stopped at and then keep on going. Or we could just put them all in one block	
6	Practitioner	So how is that going to sound? Can you hum it for me? Can you	
7	Owen	Instead of justit's gonna take, like, steps up and it's gonna go every other note. It's gonna goit's gonna start higher, then we're gonna go all the way high, then we're gonna start, uh, a little bit lower, then were gonna go down, uh, to the next octave then your gonna just do nothing. Then your going to use a couple more notes on the next octave. Like uhh	
8	Practitioner	So you're saying, for example, we go A, B, C, D. Then the next block would be	
9	Owen	No, C, D, DC, D, E, F, G, A, B, CNext octaveC, D, D	
10	Practitioner	Ok, I see what you are saying, same notes, just an octave higher.	
11	Owen	Yeah, just an octave higher. Because that is what everyone else is saying and they want it to build up and um	
12	Practitioner	Build up to what though?	
13	Owen	Build up uhhBuild up to the red. And, and if it is already past the red, we'll just, um, knock it down and do this (points to block on the screen)	

Table 2: "Final Activity" whole-class excerpt

Both Ali and Owen take up other students' intuitive thoughts and use them to try and come up with a solution to the problem. They also seem to move fluidly up and down the musical structural ladder by being able to think about the melodic phrases that are being heard (e.g., mid-level structure) and how those phrases may impact the entire piece as a whole (e.g., higher-level structure) and how concepts like the pitches of notes (e.g., low-level structures) may be used.

Ali (line 3) mentions that she does not like the beginning of the piece and agrees with Sam that the tune should be more techno sounding. Her explanation of how the beginning sounds using metaphors like "weird movie" and "really scary" highlights her focus on the genre and style of the piece (high-level structure). To find a solution on how to make the song more techno, echoing Sam's earlier statement along with other classmates sentiments, she suggest changing the instruments. This is important because, to this point, the students have tried speeding up the tune, which was not effective. Other than starting over and making new blocks, the other alternative is to change the instruments. By focusing on the instrumentation, Ali draws on her own intuitive knowledge about what it means for a song to be techno by deducing that changing the speed did not work—as suggested by Sam—but changing the instrument may impact the overall tune.

It is important to remember that considerable time has been taken in discussing and agreeing what "techno-adventuresome" music was and sounded like and also constructing a beginning to the tune. It was evident that the students were not happy with what has been done to this point. The practitioner asks for suggestions on how the song could be changed for it to meet the goal of being "techno-adventuresome" (line 4). Owen then devises an elaborate plan for addressing the issues being raised. Like Ali before, Owen takes in the

suggestions of his peers and constructs a plan of action he think will work. Specifically, he states "...that is what everyone is saying..." indicating that he has heard what everyone has been saying and his plan might work in order to solve the problem at hand (line 11).

The movement up and down the structural musical ladder is apparent in his explanation. Owen's initial description of his solution (line 5) indicates he has thought through what he wants to do, but it is incomplete. It focuses on both the mid-level structure (e.g., making a new block) and moves fluidly to a low-level structure about what the block should be (e.g.,notes and their function). When the practitioner asks for clarification (line 6), Owen then is able to refine his thinking and get rather specific about his plan (line 7) again, focusing on low-level structures. When the practitioner asks for further clarification (lines 8 and 10) Owen is able to summarize his plan and relate it to his peers issues with the tune (line 11) indicating that he has not only thought about how the notes should function in his plan, but how they will impact the overall tune signifying a movement to a more high-level structure.

Conclusions and implications

The connection to reflecting-in-action suggests that even younger students, who are not professionals or experts in a domain (e.g., music), can use their intuitions to reflect on what it is they are doing, similar in ways to what professionals do. This also suggest that the reflection (e.g., the talk) needs to be closely tied to what the student is doing in the moment so that the reflection becomes more meaningful and promotes further construction of knowledge beyond, for example, mid-level structures (e.g., what they already know). More interesting, especially to the CSCL community, is that when students have a commonly shared goal (e.g., composing a piece of music), their reflections-in-action become building blocks for others to construct their understanding. It should be noted that the above excerpt was taken at during the last project of the curriculum. However, even at the beginning of the curriculum, students were incorporating someone else's ideas into their explanations of what was happening in the composition.

Intuitions, both their impact on learning and how to encourage their use despite their correctness, is largely overlooked in education research. Intuitions help us in seeing the whole of a problem and fill in gaps in our experiences to give us a complete picture of how things work in the world (Bruner, 1977; diSessa, 1993; Fischbein, 1982; Noddings & Shore, 1984). Literature in the Learning Sciences and elsewhere tends to treat intuitions as a 'catch-all' phrase that lacks a clear operational definition (c.f., Clement, 1993; Resnick & Wilenski, 1998; Zietsman & Clement, 1997) and seems to encompass what people know, yet do not know how they have come to know (Noddings & Shore, 1984). Intuitions are extremely useful in understanding both learning and teaching within specific domains (e.g., music) (Bamberger, 2013; diSessa, 1993; Schön, 1983; 1987).

More research needs to be done to understand what types of reflection-in-action activities encourage collaboration, the size of the groups working together, and the domains that this would be ideal for. Creative activities like music composition provide learners with the experience of doing what an expert does, or as Resnick and Wilensky (1998) state, it gives the student an opportunity "dive in" (p. 155) or play the role of a music composer. This "diving in" allows learners to make use of what they know how to do already. Music composition and intuitions are relatively understudied in areas of educational research like CSCL and the Learning Sciences and this study provides a way in which to investigate them. This research can solidify the idea that intuitions should not just be used as a 'catch-all' phrase to explain what cannot be explained. Intuitions provide key foundations to critical thinking and problem solving if there is a clear foundation given for intuitions and how it relates to the researchers theoretical framework.

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The 3R Orchestration Cycle: Fostering Multi-Modal Inquiry Discourse in a Scaffolded Inquiry Environment

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Abstract: This paper reports on second and third iteration classroom trials of Common Knowledge (CK2 and CK3 respectively) – a pedagogical and technological innovation that supports teacher orchestration of inquiry discourse occurring in the digital CK environment and face-to-face in the classroom. CK facilitated the scaffolding of grade 5/6 students through phases of collaborative biodiversity (CK2) and astronomy (CK3) inquiry. Using tablets, students contributed to a community knowledge base that was publicly displayed on an interactive whiteboard (IWB). The IWB visualized the community's idea flow, enabling learners to sort their ideas along socially-negotiated categories. Inquiry work done in the CK environment affected the knowledge work done in the face-to-face classroom discussions, and vice versa. We observed that teachers used an orchestration cycle of Reflect-Refocus-Release (3R) as a means of managing this blended learning environment. A comparison of teachers' Reflect discourse structures between both iterations indicate such patterns vary with inquiry task demands.

Keywords: orchestration, discourse, inquiry, collaboration, blended learning environment

Introduction and objectives

Advances in computer supported collaborative learning (CSCL) research have yielded technologies where discourse plays a fundamental role of collaborative knowledge building (e.g., Group Scribbles - Roschelle et al., 2007; ConcertChat - Stahl, 2006). Some CSCL environments have used the technology to "script" collaborative problem solving processes within a community (e.g., CollPad - Nussbaum et al., 2009). Other CSCL environments scaffold online discourse and add an element of crowd sourcing (e.g., "likes" for promising threads; PeppeR - Hewitt et al., 2013) for collaborative learning in a face-to-face (F2F) environment (e.g., InterLACE - Coopey et al., 2013; Moodle - Dougiamas & Taylor, 2003; Knowledge Forum - Scardamalia, 2002). Inquiry discourse can be viewed as a social process of meaning construction (Vygotsky, 1962). Such discourse may include argumentation (Kuhn, 1993), theory-building (Bereiter & Scardamalia, 2012), or explanation building (Sandoval & Reiser, 2004). However, the underlying goal of all these environments is the pursuit of deeper understanding and the epistemic practice of science (Nickerson, 1985).

In learning environments that aim to engage students as a knowledge community in collective inquiry toward the production of knowledge as a product, there is typically a heavy reliance on teacher-guided oral community discourse (Slotta & Najafi, 2010). However, this places a serious burden on teachers to orchestrate inquiry in blended learning environments (i.e. F2F classrooms incorporating computer-mediated activities), as they must continuously traverse online and F2F environments to guide discourse towards productive paths of inquiry. If technology for guiding inquiry and discourse is to minimize teachers' "orchestration load" (Dillenbourg, 2012), we must first understand how teachers guide such multi-modal inquiry and discourse, in order to design scaffolding technology to relieve some of their orchestration load. Hence, there remains a need for research of discourse and activity sequences in technology-mediated inquiry discourse in the successful application of community note-sharing environments in elementary classrooms.

We continue to innovate on the development of Common Knowledge (CK) – a content-agnostic pedagogical and technological note-sharing application for collaborative inquiry. Using tablets, students contribute to a community knowledge base that is publicly visible from the IWB. This interactive display visualizes the community's idea flow and enables learners to sort their ideas by topic. Building on the

affordances of the second iteration (CK2), the third iteration (CK3) incorporates an inquiry script, scaffolding the community through phases of science inquiry: Brainstorm, Propose, and Investigate. Students *brainstorm* questions and theories, by contributing Brainstorm notes; students then *propose* research trajectories and design experiments to test their theories, by contributing Proposal notes. Such contributions inform subsequent work in fluid interest groups (each supported by an interest-specific shared interactive display), in which students *investigate* the proposed research, sharing findings via Report notes, and making inter-group connections. This paper will report on CK2 and CK3 classroom trials, presenting an observed Reflect-Refocus-Release (3R) cycle of teacher orchestration that occurred across multiple iteration enactments, and a comparison of teacher discourse structures occurring in the Reflect orchestration phase.

Theoretical perspective

Knowledge building

Our research is grounded in the theoretical tradition of classrooms as Knowledge Communities, where community members value a diversity of expertise, metacognitive awareness, a common goal of advancing the collective knowledge, and a means by which to share learning (Bielaczyc & Collins, 1999). Knowledge Building is one of the most prominent examples of the knowledge community approach and has been advanced as a powerful way of learning (Bielaczyck, 2011; Hmelo-Silver & Barrows, 2008; Scardamalia & Bereiter, 1996). Students engage as a knowledge community in collaborative inquiry discourse with peers and teachers to improve emergent understanding, and are scaffolded by a CSCL environment such as Knowledge Forum (Scardamalia, 2002).

Knowledge community and inquiry

The Knowledge Community and Inquiry (KCI - Slotta & Najafi, 2010; Slotta & Peters, 2008) approach has been advanced as a more accessible model for real-world classrooms and their inevitable "extrinsic constraints" (Dillenbourg et al., 2012), such as time, curriculum relevance, and assessment. In KCI, students are scaffolded to work as a knowledge community in building a collective knowledge base, which becomes a resource for subsequent scaffolded inquiry activities, targeting specific learning goals (Peters & Slotta, 2010; Slotta & Najafi, 2012).

The role of discourse in a knowledge community approach

Language has been shown to be a central mediator of thinking and learning within a knowledge community (Wertsch & Smolka, 1994), as communication with peers and teachers generates new meaning or insight about next steps for inquiry (Sfard, 2007). Reciprocal Teaching (Palincsar & Brown, 1984) was conceived as a transitional discourse structure to help students progress from teacher-mediated dialogue to independent small group discussion, with a gradual fading of teacher direction and structure. Bereiter and Scardamalia (2008) define five levels of classroom dialogue, varying in their levels of structure and teacher directedness.

O'Connor and Michaels' (1996) analysis of "revoicing" – the oral or written re-phrasing of a student's contribution by another participant (often the teacher) – describes how teachers orchestrate group lessons through language socialization into intellectual practices, by positioning students in relation to each other and aligning them with the academic content at hand. Teacher "revoicing" of student comments can advance discussion by (1) using student contributions to introduce new ideas or terminology, (2) reframing student contributions to steer the discussion in toward a productive direction, (3) positioning a student in relation to the argument by attributing his or her comment to a stance, or (4) creating alignments and oppositions within an argument – thereby positioning students in relation to their peers (O'Connor & Michaels, 1996). "Revoicing" thus offers a means for teachers to orchestrate classroom discourse and foster idea growth, reinforcing collective epistemology and guiding inquiry progression.

Scripting and orchestration

Knowledge community approaches typically rely on the teacher to foster community knowledge sharing and collaboration. Yet collaborative learning research has shown that learners need guidance to engage in such "high-level" collaboration processes (Weinberger et al., 2010). To compensate for learners' lack of collaboration skills (i.e. lack of internal collaboration scripts), external collaboration scripts may be used initially and gradually faded as learners develop their collaboration skills internally (Fischer et al., 2012). CK incorporates collaboration scripting (involving elements of crowd sourcing and interest-based social groupings) and an inquiry script (comprised of successive inquiry phases) designed to support the community's eventual knowledge convergence. The enactment of even the most thoughtful pedagogical designs, whether facilitated by

technology or not, requires thoughtful management of students, activity, resources, technology, and time – what Dillenbourg contentiously (Roschelle, Dimitriadis, & Hoppe, 2013) redefined as 'orchestration': "how a teacher manages, in real time, multi-layered activities in a multi-constraints context" (Dillenbourg et al., 2012; p.1). Indeed, one CK design objective was to minimize teachers' cognitive load, what Dillenbourg calls "orchestration load" (2012). As an "orchestration tool" (Dillenbourg et al., 2012), the inquiry and collaborative scripts at the heart of CK's technological design and topic-focused visualizations, enable the knowledge community to cope with their incoming ideas arising from all members ostensibly "talking" simultaneously, and offer a technology structure to manage the community's inquiry process.

The study lends new insight into how forms of knowledge building can be integrated into a KCI curriculum and KCI-scripted technology design. It further offers an example of how teachers may orchestrate these to foster collaborative inquiry toward productive trajectories and forms of discourse, by which they facilitate the knowledge community's inquiry progress.

Method

This study is part of a program of design research to investigate theory and practice of the KCI model, and is situated within the broader multi-year "Embedded Phenomena & Inquiry Communities" (EPIC) collaborative research project (Moher & Slotta, 2012). The teachers and the school's vice principal—all co-authors on this paper and masters of Knowledge Building practice—have been included in iterative CK co-design cycles (Roschelle, Penuel, & Shechtman, 2006) since 2011. Data sources from our observations of grade 5/6 classrooms included field notes, video recordings, teacher and student interviews, and data logs of CK discussions. A grounded approach (Glaser & Strauss, 1967) to video coding was used to determine teachers' orchestrational and discursive scaffolds. Participants were two veteran grade 5/6 teachers, 'Brad' and 'Jen', in a private elementary school located in a large Canadian city, with 23 students each (approximately equal numbers of grade 5 and 6 students). By our third iteration of CK, Brad had been teaching for 8 years, and Jen for 5 years. The school has an emphasis on inquiry and Knowledge Building pedagogy.

In enactments of CK2, students were engaged for nine weeks during the fall of 2011 in a biodiversity inquiry curriculum—WallCology Embedded Phenomena— where they were tasked with investigating a virtual "live" ecosystem located "within" their classroom's walls (Moher & Slotta, 2012). CK2 was integrated into the broader suite of WallCology inquiry tools that guided students through six successive content-based inquiry phases, in which they were tasked with determining each species' life cycle, environmental and food preferences, and the ecosystem's food web. Students entered observations and CK notes about the four habitats located within their classroom walls, observed through a "WallScope" (a large monitor) mounted on each wall. In each phase, students could continuously access their peers' CK notes from tablets, as well as compose CK notes, incorporating pre-programmed science content and process keyword tags that were specific to the inquiry phase at hand. Online CK2 discussions were integrated into the inquiry curriculum, with specified discussion goals. Teachers also launched spontaneous CK2 discussions, as they felt were warranted.

CK3 was a content-agnostic standalone application, which closely coupled an inquiry script with a technology script. Knowledge communities were scaffolded through phases of astronomy inquiry, towards knowledge convergence that was connected to teachers' curriculum goals of addressing the topics of gravity, scale, and nested systems. It also aimed to capitalize on the physical classroom layout as an additional dimension of collaboration scripting and collective knowledge mapping. This was a 9-week grade 5/6 Astronomy inquiry progression supported by CK3, and was enacted in the spring of 2013.

To investigate *teachers' orchestration of classroom activity*, the cumulative amount of classroom time teachers allocated to inquiry activity involving CK3 over the 9-week enactments was noted. A grounded approach to video coding of CK2 and CK3 enactments was used, with coarse-grain coding focused on teachers' activity orchestration. Any teacher-guided community oral discussion involving at least one student speaker and lasting for at least one minute, was coded as a community discourse episode ("CDE"). Student-driven activities that involved Common Knowledge were coded as "SD-CK". Video data of two 90-minute CK2 classroom periods and three 90-minute CK3 classroom periods from each teacher were chosen for finer grain coding, based on the richness of CK-driven classroom discourse and opportunities for CK note contributions during the same session. We sought to analyze the class periods with the most uninterrupted usage of CK, in order to capture what might be construed as characteristic inquiry orchestration patterns. Finer grain coding focused on teachers' discourse patterns during CDEs, to *discover possible discourse patterns* emerging from teachers' moves.

Findings and discussion

Teachers' activity orchestration

Video coding of Brad's and Jen's CK2 and CK3 enactments for teacher-guided community discourse episodes ("CDE"), and student-driven activities that involved Common Knowledge ("SD-CK") revealed that students participating in CK3 enactment in both Brad's and Jen's classrooms spent more time in student-driven activities than in teacher-guided activities. This is reversed from the pattern seen in CK2 enactment, where teacher-guided activity was favored (see Figure 1). Jen in particular, showed a dramatic shift in her allocation of classroom time from CK2, when 55% of the time in which CK2 was a focus was given to teacher-guided community discussion episodes (CDE); to CK3, where only 24% was given to CDE. In CK3 enactment, students were given more time to work independently in the CK3 environment, enabling them to reflect more meaningfully (as evidenced by their CK3 notes) on their own CK3 contributions and that of their peers.

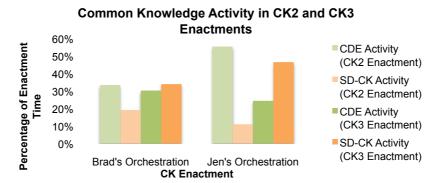


Figure 1. A comparison of teachers' orchestrated time in CK2 and CK3 enactments, spent on community discourse episodes (CDE) and student-driven inquiry in the CK environment (SD-CK).

It is interesting to this study that changes to our script and technology features could induce such a large behavioral shift in classroom discourse structures. One possible explanation for this shift is that CK2 was more content-oriented (i.e., WallCology investigations), while CK3 was more process-oriented (i.e. student-driven astronomy inquiry), with no predetermined content or referent for discourse. As such, discussions during CK2 enactment were more content–oriented, and less process-oriented; whereas discussions during CK3 enactment were more process-focused, looking for patterns and connections within the knowledge base. Furthermore, the student-driven nature of CK3 content resulted in the teacher spending more time in small group interactions with student collaborators working on common inquiry goals. This resulted in more orchestration time given to student-driven inquiry activity in the CK3 environment, and less time given to community reflection discussion.

Qualitative video analysis and closer examination of the sequencing of CDE and SD-CK events for CK2 and CK2 enactments, revealed that teachers guided their communities towards productive inquiry through rounds of CDE in which they scaffolded students to *reflect* upon and discuss their peers' CK3 notes, culminating in teachers' instructions that *refocus* the community's subsequent inquiry activity, whereupon students were *released* to pursue their inquiry trajectories (i.e., SD-CK) – resulting in further note contributions to the community knowledge base. This 3R cycle (Reflect-Refocus-Release) figured prominently in teachers' orchestration of their enactments. Reflective discourse was pivotal in helping students develop awareness of their community's state of knowledge, achieve knowledge convergence, and receive teacher guidance towards productive inquiry.

Figure 2 provides more details about teachers' orchestration of CK3 activity during the three classroom sessions of CK3 enactments that were selected for further analysis. The top level of each teacher's panel (i.e., "# of Notes") presents students' note contribution activity corresponding to SD-CK events. During the three class sessions, Brad's students contributed 21 Brainstorm notes (including Build-on notes from peers), 19 Proposals, and 15 Reports, while Jen's students contributed 64 Brainstorm notes (including Build-ons), 39 Proposals, and 4 Reports. The number of notes shown begins with a non-zero value, as some notes had been contributed in class sessions preceding those that were coded.

CK3 Enactment Activity in Brad's Class

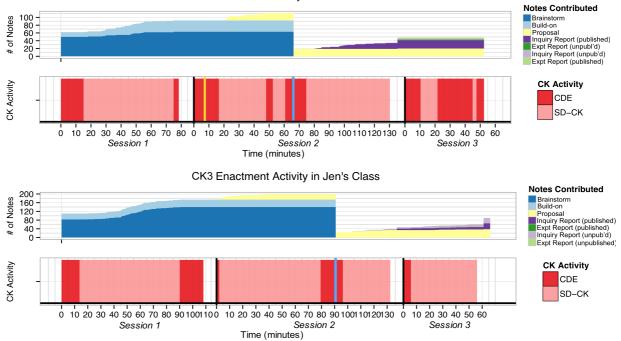


Figure 2. Enactment timeline for Brad's (top) and Jen's (bottom) orchestration of CK3 activity during their three selected class periods of CK3 enactment. The black vertical lines delineate the end of one period and the beginning of the next period. The yellow vertical line marks when Brad initiated the Propose phase of inquiry (Jen initiated the Propose phase in a different session). The blue vertical lines mark when each teacher initiated the Investigate phase of inquiry. For each teacher, the bottom (red/pink) level shows the orchestration sequencing of CK3 activity. The top level shows students' contributions of different types of CK3 notes.

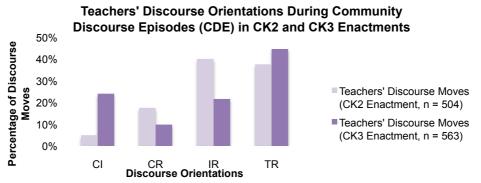
The red/pink "CK Activity" graphs in Figure 2 illustrate teachers' pacing and sequencing of the Reflect (CDE, red) and Release (SD-CK, pink) phases of the 3R orchestration cycle. Students produced knowledge artifacts during the Release phases, in the form of CK3 notes – as can be seen in the increase of notes (see "# of Notes" graphs in Figure 2) during the Release phases. Similar analyses were done on two selected class sessions of each teacher's CK2 enactment, and also showed increases in note contributions during SD-CK (Release) events. For enactments of both iterations, teachers used students' CK notes to launch and guide F2F community discussion during the Reflect phase of their orchestration. Teachers often concluded a discussion with Refocus instructions intended to provide direction to students about strategies to address issues that emerged from that discussion.

Teachers' discourse patterns

The continuous back-and-forth movement between student-driven activities in the CK environment (Release) and community discourse events (Reflect), each informing the other, was guided by teachers' Refocusing instructions. These instructions emerged naturally from student input during Reflection community discussions. A closer examination of teachers' discourse moves during these discussions was done to investigate how they facilitated the discussions towards productive trajectories and guided ensuing student-directed inquiry work for the subsequent Release phase of activity orchestration.

A grounded approach to video coding of teachers' discourse moves during their facilitation of community discourse events (i.e. Reflect phase of orchestration) in their two selected CK2 enactment sessions and their 3 selected CK3 enactment sessions, revealed four orientations of teacher-initiated exchanges: (1) Teacher Reflection (TR), in which the teacher "revoices" or engages in a personal reflection about recent ideas or progress; (2) Individual Student Reflection (IR), in which individual students or groups were posed an inquiry question; (3) Whole Class Reflection (CR), in which the teacher poses a reflection question to the classroom as a whole; and (4) Class Instruction (CI), in which the teacher issued straightforward instructions to the class. Teachers used these orientations to guide community discourse, promote reflection on the community's collective knowledge base, and engage the community in discursive knowledge work.

Since Brad and Jen had similar discourse orientation patterns to each other, in their enactments of both iterations, the distribution of teachers' discourse orientations were collapsed across teachers and a comparison was done between teachers' discourse orientations for CK2 and CK3 enactments (see Figure 3). Notably, teachers placed less emphasis on community reflection (CR) and individual student reflection (IR) in CK3 enactment than they had in CK2 enactments, with increased emphasis on community instruction (CI) and teacher reflection (TR) in CK3 enactment. This shift in teachers' discourse patterns may again be attributed to the differing inquiry task demands between content-focused CK2 and process–focused CK3.



<u>Figure 3</u>. A comparison of teachers' discourse orientations during community discourse episodes (CDE), as a percentage of teachers' total discourse moves, over their selected class periods of CK2 and CK3 enactments. Teachers' discourse orientations: community instruction (CI), community reflection (CR), individual reflection (IR), and teacher reflection (TR).

All coding was done by the first author, with code key refinement done through a process of inter-rater checking with this study's second rater, who independently coded 20% of teachers' video-recorded discourse moves during their selected enactment sessions, for the four discourse orientations (CI, CR, IR, TR). Inter-rater agreement was 94%, and the inter-rater reliability was found to be Cohen's Kappa = 0.91.

Teachers used TR discourse orientations to model their knowledge work processes as they interacted with students' CK note contributions. Such processes may begin with identifying common themes, unique perspectives, and knowledge gaps, then move into relating ideas to prior knowledge or prior experiences, assessing the community's current epistemic approach, and suggesting a new epistemic approach. Teachers also used TR discourse orientations to amplify students' ideas in the public sphere, "revoicing" ideas, sometimes fusing this with their own phrasing toward a purposeful direction and seeking student validation of—or response to—their particular "revoicings". Such discourse moves can be seen as disrupting the traditional teacher-student power dynamic, since the student is now positioned to evaluate what the teacher said. CR and IR orientations were often employed to empower students through role-casting individual students (IR) or the community-atlarge (CR) as legitimate participants of inquiry (e.g., questioner, observer, theorizer, inquirer), while simultaneously seeking students' explanations of what they had shared in CK notes or spoken comments. CR and IR orientations were also used, less frequently, to encourage students to verbally build-on an idea, synthesize multiple ideas or multiple CK notes, comment about the current epistemic approach, or suggest a new epistemic approach to pursuing the inquiry.

Conclusions and implications

In a CK-mediated classroom, students engage in collective inquiry in an online notes-based environment and in teacher-guided discussions in the classroom environment. The inquiry work done in one learning environment affects the knowledge work done in the other, and vice versa. We observed that *teachers utilized an orchestration cycle of Reflect-Refocus-Release (3R)* as a means of managing this complex balance. Teachers' refocusing instructions were critical in guiding inquiry work done in the CK environment, and the work done in the student notes was vital to informing teachers' scaffolding of whole class reflections.

An interesting shift in the allocation of instructional time occurred between CK2 and CK3 enactments, evidently as a result of the differing forms of inquiry (and differing technology scripts to support these) in the two enactments. CK2 was integrated into a more content-focused WallCology curriculum progression, with teachers allocating more time for community discussion (i.e., Reflect) and less time for independent student work periods (i.e., Release). CK3 scaffolded students through a more process-focused student-driven inquiry progression, with teachers allocating less time for community discussion, and more time for independent student work periods. This suggests *discourse patterns/structures vary with inquiry task demands*. Perhaps teachers felt

a greater need to guide student inquiry differently in both cases, spending more time in small group interactions during students' work period, to guide the process-focused CK3 enactment.

Teachers' discourse moves during community discourse episodes in all three iterations revealed the presence of *four discourse orientations: class instruction (CI), community reflection (CR), teacher reflection (TR), and individual reflection (IR)*. Once again, there were observed differences in discourse patterns between CK2 and CK3 enactment, in terms of the degree to which the teachers used each of the four orientations. A substantial reduction in the use of IR and CR orientations was seen in CK3 enactment, accompanied by an increase in community instruction (CI) and teacher reflection (TR). These different patterns are also likely a consequence of shifting task demands across the two iterations. Teachers, in their discourse, must move the class through the inquiry script, using the technology environment as an orchestrational tool. Between CK2 and CK3, profound design changes were made to the technology and inquiry script. CK3 shifted away from content-embedded technology features (e.g., pre-programmed keywords related to inquiry phase at hand) and content-driven inquiry script, towards content-agnostic technology features and a process-driven inquiry script. These design shifts clearly impacted the forms of discourse arrived at by the teachers as they followed the pedagogical script.

However, a limitation of CK3's focus on scripted inquiry progression of autonomous student inquiry phases is that it may have hindered the breadth of students' investigations. Teachers did remark about this trade-off, and should be a consideration in any future design efforts.

By engaging students in reflective note-sharing as part of a scripted inquiry progression, we were able to investigate how CK could help students and teachers engage in a Knowledge Community and Inquiry (KCI) approach. By adding CK as an inquiry scaffold, we produced a blended form of learning environment, where individual students develop and share their inquiry work within a common digital repository, motivating teacher-guided discussions, which in turn motivate new, refocused inquiry using CK. The note-sharing system becomes a tool that mediates between the two learning environments: students' collective inquiry done in the digital note-sharing environment and community knowledge work done during teacher-guided classroom discussions. Successful mediation of this blended learning environment entails the agile orchestration of inquiry progression. Hence the note-sharing system serves a dual purpose: to mediate between inquiry learning environments, and to support teachers' orchestration of the learning progression.

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Principle-Based Guidance to Foster Adaptive Teaching Practice

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Abstract: This exploratory study investigated the effects of engaging teacher-education students in collaborative lesson design activities guided by knowledge building principles on their mathematics teaching practices. The study context was a university course concerning mathematics teaching practice. Analyses focused on (a) online collaborative lesson design activities, and (b) classroom teaching practices. Results showed that the principle-based guidance (a) was conducive to progressively more collaborative knowledge work, and (b) was able to engage the participants in gradually more adaptive mathematical teaching practice.

Keywords: Principle-based, adaptive teaching, knowledge building

Introduction

An essential goal for teacher-education programs is to cultivate competent future teachers. To this end, a popular approach to teacher preparation is to help prospective teachers acquire core teaching knowledge and skills identified in literature or from exemplary model teachers (Hirsch, 1996; Slavin & Madden, 2001; Tileston, 2000). Such practices are often associated with direct instruction that encourages practices based on word-for-word teaching scripts (Adams & Engelmann, 1996; Engelmann, 1980; Sawyer, 2004; Slavin & Madden, 2001). In contrast, an alternative approach is to guide teacher-education students to assume the role of theory-builder or researcher, and to develop more adaptive disposition for sustained improvement in their teaching practices (Bereiter, 2002). The purpose of this study was to investigate whether engaging teacher-education students in principle-based knowledge-building activities during their lesson design would help them perform more adaptive teaching practices.

Mathematics teaching practices

Practice is essential to gain expertise. According to Hatano and Inagaki (1986), there are two general types of expertise: routine and adaptive. They conceptualized routine expertise as a core set of competencies that is developed through high, but rather narrow, procedural proficiency. An essential dimension of routine expertise is 'efficiency'. As argued by Hammerness, Darling-Hammond, Bransford, Berliner, Cochran-Smith, McDonald, et al. (2005), efficiency means "greater abilities to perform particular tasks without having to devote too many attentional resources to achieve them" (p. 361). In relation to teaching practices, routine expertise implies that a teacher is able to retrieve and appropriately apply a set of well-defined knowledge and skills to solve recurring teaching-related problems. When routine teaching expertise is pursued as an important goal for teacher-education, its aim is to help teacher-education students master some specified teaching knowledge and skills and apply them efficiently to solve common classroom problems. Typically, such knowledge and skills are identified through research or model teaching (Goodnough, 2003; Hirsch, 1996; Slavin & Madden, 2001; Tileston, 2000) and are useful for implementing highly structured scripted teaching (Adams & Engelmann, 1996). With routinized knowledge and skills, teachers can manage their class more efficiently, have control over what is to be taught, and cover the curricular materials more thoroughly. Previous research suggests that mastery of routinized teaching knowledge and skills improves students' academic achievements in mathematics (Adams & Engelmann, 1996). Nevertheless, there are also disadvantages of such mode of teaching practice, as it emphasizes simple tasks more than complex problem-solving. Also, the teacher can become concerned mainly with measurable learning outcomes. More importantly, this way of teaching does not take the teacher's creativity and personality into consideration (Sawyer, 2004).

In contrast to routine expertise, Hatano and Inagaki (1986) conceptualize another type of expertise—the adaptive type—as the ability and attitude to make adjustments in and add to core competencies in order to remain adaptive for future learning and development (Bransford & Schwartz, 1999; Schwartz & Martin, 2004). Unlike routine expertise, which emphasizes 'efficiency', an important dimension of adaptive expertise is 'innovation'; it means "moving beyond existing routines and often requires people to rethink key ideas, practices, and even values in order to change what they are doing" (Hammerness et al., 2005, p. 361). Accordingly, adaptive expertise in teaching implies that a teacher is able to solve recurring or novel teaching problems by improvising alternative solutions, and can keep improving these solutions (Darling-Hammond &

Bransford, 2005). When adaptive teaching expertise is deemed a primary knowledge goal to be pursued in a teacher-education program, learning (to teach) is more likely to emphasize the ability to adapt to new instructional situations and to generate fresh ideas or solutions for addressing emerging teaching problems. Typically, such knowledge and skills are difficult to pre-define, and can only be gradually developed during the process of progressive problem-solving or knowledge-building for better teaching (Hong & Sullivan, 2009; Zhang, Hong, Scardamalia, Teo, & Morley, 2011). The essence of such teaching practices is therefore not to model one's teaching after some exemplary teaching skills, but to engage in a mode of sustained improvement of one's own practices (Bereiter, 2002; Cohen, 1989; Sawyer, 2004; Darling-Hammond & Bransford, 2005; Hargreaves, 1999; Bereiter & Scardamalia, 1993).

Knowledge building

Knowledge building, also known as "deep constructivism" (Scardamalia, 2002, p. 4), is defined as a social process focused on sustained community knowledge advancement (Scardamalia & Bereiter, 2006). Unlike most educational approaches that highlight learning through acquiring and accumulating well-established knowledge (Paavola, Lipponen, & Hakkarainen, 2004; Sfard, 1998), knowledge-building employs ideas as building blocks for advancing deeper knowledge around a specific theme or topic. The importance of valuing ideas as basic units of thought or objects of inquiry can be manifested by means of Popper's (1972) 3-World epistemic conceptualization. Popper refers to World-1 as an objective, natural/physical/material world, World-2 as a subjective psychological world constructed within the human mind, and World-3 as a conceptual world constituted mainly by ideas (e.g., theories, models). He argues that ideas are the creative results of human beings (such as engineers, scientists, researchers, artists, and the like) and that all forms of human knowledge are related to the creation of ideas in a human community (Scardamalia, 2002). Bereiter (2002) further argues that ideas are conceptual objects which, once produced in a public domain, can possess a social life of their own and can be continually tinkered with, modified, and improved.

To bring about productive community knowledge advancement through improving ideas, Scardamalia (2002) proposed a set of knowledge-building principles. For example, the principle of 'idea diversity' states that "[i]dea diversity is essential to the development of knowledge advancement, just as biodiversity is essential to the success of an ecosystem. To understand an idea is to understand the ideas that surround it, including those that stand in contrast to it. Idea diversity creates a rich environment for ideas to evolve into new and more refined forms" (p. 79) (see Scardamalia & Bereiter, 2010, for detailed descriptions for all principles). Typical classroom work is usually defined by pre-specified procedures (see e.g. Dick & Cary, 1990; Mager, 1975), clear rules and scripts (cf. Sawyer, 2004), or highly structured, routinized learning activities (e.g., Merrill, 1983; Gagne, Briggs, & Wagers, 1992) that represent fixed rather than improvable classroom procedures (cf. Hong & Sullivan, 2009). In contrast, knowledge-building highlights the use of abstract principles as guidelines to illustrate some pedagogical challenges that would pave the way towards sustained knowledge advancement for the community's work (Bereiter & Scardamalia, 2006).

The present study

In the field of computer-supported collaborative learning, there have been studies dedicated to teacher learning (e.g., Barab, MaKinster, & Scheckler, 2003; Greiffenhagen, 2012; Song & Looi, 2012). Particularly, there have been studies investigating the relationships between computer-supported collaborative knowledge building and teacher preparation or development (e.g., Cesareni, Martini, & Mancini, 2011; Chan, 2011; Chan & van Aalst, 2006; Laferriere, Lamon, & Chan, 2006; van Aalst & Chan, 2001, Oshima et al., 2006) Nevertheless, few studies have actually explored specific instructional models or approaches in the knowledge building area for fostering adaptive mathematic teaching practices. To address such a challenge, this study proposes and tests a principle-based design approach (Hong & Sullivan, 2009; Zhang, Hong, Scardamalia, Teo, & Morley, 2011). Overall, the principle-based instructional design model is very different from conventional instructional design models that are inclined to foster routinized practices; for example, task-driven instructional design models (Dick & Carey, 1990), Criterion Referenced Instruction (Mager, 1975), and Component Display Theory (Merrill, 1983). Such design approaches tend to emphasize the importance of employing well-defined procedures, rules, and/or componential tasks (Reigeluth, 1996) in order to help students acquire pre-defined knowledge and skills. In contrast, the proposed principled approach is characterized by the use of abstract principles to guide students' knowledge work. In the present study, the following three knowledge building principles were used, "idea improvement", "epistemic agency", and "community knowledge" (see detail below in the Method section), and the present study intends to examine the proposed principled instructional design approach by answering the following questions: (1) How do the principle-based knowledge building activities affect participants' online

performance and knowledge work (i.e., lesson design activities)? (2) How do the principle-based knowledge building activities affect participants' mathematics teaching practices?

Method

Study design, participants, and instructional context

This case study gathered on-site data embedded in a course context. The duration of the study was a year—i.e. two semesters, with each semester lasting about 16 weeks. Participants were nine teaching-education students. The participants were planning to become middle-school mathematics teachers in Taiwan after graduation, so took this university-level course entitled Middle School Mathematics Teaching. Major instructional activities throughout the academic year were described as follows:

- (1) Lesson design ideas: Participants were guided to generate initial lesson ideas; then, they worked on the details such as setting instructive goals, preparing learning materials and worksheets, etc. One thing to note is that before this activity, students were also encouraged to reflect back on the teaching problems they have encountered previously in order for them to go beyond their best practice.
- (2) Beyond best practice: Based on lesson design ideas, the participants performed their teaching practices in class, with the rest of the classmates serving as the audience and critical reviewers. On average, each teaching practice took about 25 minutes. All nine students in this course took turns to practice teaching. There were in total three lesson design cycles implemented in the whole school year.
- (3) Peer feedback: The teaching performance was then under critical review by all other classmates who would individually comment on the practiced teaching by identifying issues, acknowledging strengths, and giving constructive feedback for improvement, etc.
- (4) Co-design discussion: All participants were further guided to collaboratively discuss some design questions such as: "If you were to design this same lesson, how would you do differently to improve the teaching practices?"; "What is your main design idea?"; "Why is it useful?"; "How is it going to improve this particular teaching?" etc..
- (5) Reflection: The student who practiced her teaching could further reflect on her video-taped teaching, and online peer-feedback and co-design discussion comments, etc., in order to summarize all comments and rise above previous lesson design ideas. Then, she will start to prepare for the next design cycle. In addition, the participants were also required to write reflection notes at the end of each practice and a reflection paper at the end of the course.

The lesson design activities were guided by a principled design approach, in particular, by using the following three knowledge building principles: (1) idea improvement, (2) epistemic agency, and (3) community knowledge. To elaborate, the principle of "idea improvement" highlights the importance of treating all lesson ideas as improvable and that "[p]articipants work continuously to improve the quality, coherence, and utility of ideas. For such work to prosper, the culture must be one of psychological safety, so that people feel safe in taking risks-revealing ignorance, voicing half-baked notions, giving and receiving criticism" (p. 79); the principle of 'epistemic agency' states that "[p]articipants set forth their ideas and negotiate a fit between personal ideas and ideas of others, using contrasts to spark and sustain knowledge advancement rather than depending on others to chart that course for them. They deal with problems of goals, motivation, evaluation, and long-range planning that are normally left to teachers or managers" (p. 79); and the principle of 'community knowledge' states that "[c]ontributions to shared, top-level goals of the organization are prized and rewarded as much as individual achievements. Team members produce ideas of value to others and share responsibility for the overall advancement of knowledge in the community" (p. 80). The above principles were purposefully selected because ideas (as building blocks of knowledge), agents (as knowledge workers), and community (as the context for knowledge interaction and advancement) represents three essential knowledge-building components. These principles were implicitly integrated into the lesson design activities, rather than explicitly taught in class. For example, to integrate the "idea improvement" principle into the lesson design activities, participants were encourage to reflect on the authentic teaching problems they previously encountered, to generate potential lesson design *ideas* for solving these problems, and to improve one another's lesson *ideas* during the *feedback* and *co-design discussion* activities; for the "epistemic agency" principle, students were encouraged to take charge of the entire lesson design process from producing initial lesson *ideas*, *practicing* their teaching, negotiating with peers about *feedback* and *co-design* activities, to becoming a critically *reflective* practitioners; for the "community knowledge" principle, students were encouraged to work collaboratively as a community by engaging in *idea* exchange, *feedback*, and *co-design discussion* activities. It is important to note that all the lesson design activities were only guided by the principles. Students were not required to practice according to any teaching scripts for acquiring certain pre-scribed core teaching knowledge.

Data source and analysis

The main datasets came from (a) participants' online lesson design activities, and (b) video-taped teaching practices. Moreover, students were required to write reflection notes after each teaching practice and a reflection paper at the end of the course. Using mixed-analysis approach, online collaborative activities were quantitatively analyzed, while online feedback/co-design/reflection comments, and teaching videos were content-analyzed. Using Chi's (1997) coding techniques, qualitative data were quantified for performing inferential statistics. The following provides more details.

First, online activity data recorded in the online database were analyzed focusing on two areas: (a) online activities (e.g., note creation and reading) and social dynamics (e.g., network density), and (b) the online feedback/co-design/reflection comments in the three lesson design cycles. Student online activities were analyzed by means of non-parametric Wilcoxon signed rank tests. This analysis was employed to measure the difference in terms of the amount of online activities between the two semesters. In addition, social network analysis was used to examine network density (which is defined as the sum of the values of all ties divided by the number of possible ties) (Wasserman & Faust, 1994); the higher the number of the density, the stronger the social dynamics of a community is suggested. In addition, feedback/co-design/reflection comments or suggestions to a possible course of improvement action were used as unit of analysis and they were parsed from a note if a note contained more than one specific comment/suggestion for a clear course of action for teaching improvement (e.g., suggesting to give students more response time when asking a question). Content analysis on participants' collaborative knowledge work based on the feedback/co-design/reflection comments was then performed. Zhang et al.'s (2007) concept of 'inquiry thread' was employed to trace participants' collective design improvement for teaching practice. Using an open coding process (Strauss & Corbin, 1990) to examine all 368 feedback/co-design/reflection comments recorded in the database, as a result, 12 different inquiry threads under two broad types of teaching practices were identified as follows: (1) efficiency-oriented (including "control over lesson plan", "control over teaching strategies", "control over class activity", "control over presentation skills", "control over what to teach", and "control over the use of teaching aids"; (2) innovation-oriented (including "adaptability in teaching design", "flexibility in teaching strategies", "interactive discussion in class", "open and engaging learning environments", "improvised learning activities", and "creative use of learning materials"). As an example, a student commented, "I realized that I should not spend too much time talking with students during my teaching practice so that I can more efficiently finish my planned teaching practice in time." (S6) and this comment was categorized under the "Control over lesson plan" thread theme. Two coders independently categorized all comments into different inquiry threads and a Kappa coefficient was calculated to be .72. Additionally, using the number of feedback/co-design/reflection comments contributed in one particular teaching practice or in a given inquiry thread, the number of collaborators who worked together in a teaching practice or in an inquiry thread, and the number of reads (i.e., the number of times online comments were read or referred or reflected by the participants in the database) as indicators, Wilcoxon signed rank tests were employed to illustrate whether there were any differences between efficiency-oriented and innovation-oriented teaching practices in terms of students' lesson design efforts.

Regarding teaching practices, data mainly came from video-taping of students' teaching practices. In addition, participants' reflection notes written after each teaching practice were used as complementary data. Using activity as unit of analysis, the videotaped teaching practices were parsed from the video and classified into various teaching activities. Next, classification of each activity during teaching practices was confirmed by the participants themselves. Then, the activities were content-analyzed based on a coding scheme highlighting three types of instructional activities (Collins, 1996): passive, active, and interactive learning. The passive mode highlighted instructional activities (mainly teacher-led) such as demonstration, direct instruction, lecture, asking factual questions, and the like. The active mode highlighted students' self--directed learning activities, such as hands-on exercises, independent work, quizzes, and the like. The interactive mode highlights team-based interactions (e.g., group discussion, group work, debate, or collaborative problem-solving). For the purpose of analysis, this study examined the percentage of time spent on each mode of activity for each of the four different teaching practices. Two coders independently coded each class activity into a mode. The inter-coder kappa was calculated to be 0.91.

Results and discussion

In this course, students were guided, under three knowledge-building principles, to work collaboratively as a community to help one another improve their lesson design and practice. To this end, they contributed design ideas online and collaboratively worked with, and reflected on, these design ideas. All the online design activities were documented in the online database. First, Table 1 shows overall online collaborative activities. Throughout the two semesters of a school year, participants contributed a total number of 160 notes (M=17.8 and SD=4.29) in the first semester and 242 notes (M=26.9 and SD=2.52) in the second semester. There was a significant increase from the first to the second semester for three main online collaborative activities, including number of notes created, number of notes read, and number of notes built-on.

A other inter	First semester		Second s		
Activity	Mean	SD	Mean	SD	z value
No. of notes created	17.8	4.29	26.9	2.52	-2.55**
No. of notes read	140.2	32.94	205.9	56.07	-2.67***
No. of notes built-on	11.3	2.49	19.9	1.90	-2.68***

Table 1. Summary of major online activities in Knowledge Forum (N=9)

Second, content analysis on students' notes revealed that there are 12 emerging inquiry threads that were developed from a total of 368 feedback/co-design/reflect comments contributed in the online database throughout the school year. To explore the collaborative design processes among participants, analysis was performed to look into how collaborative design activity was sustained over time. Overall, there were more collaborative design efforts towards improving efficiency-oriented teaching practices than innovation-oriented teaching practices, as indicated by the number of comments (M=9.22, SD=3.45, for efficiency-oriented practices; M=4.41, SD=3.05, for innovation-oriented practices; z=-3.56, p<.001), the number of collaborators (M=6.26, SD=1.70, for efficiency-oriented practices; M=3.74, SD=2.46, for innovation-oriented practices; z=-3.16, p < .01), and the number of reads (M=67.41, SD=27.28, for efficiency-oriented practices; M=32.70, SD=23.25, for innovation-oriented practices; z=-3.48, p<.001). But when looking into each individual lesson design cycle over time, it was found that there was progressive change in collaborative design efforts towards less routinized teaching practices and more adaptive teaching practices from the 1st to the 3rd design cycle. Specifically, in the 1st cycle, collaborative design effort towards improving teaching practices was more routinized than adaptive, as indicated by the number of comments (M=11.67, SD=3.12, for efficiency-oriented practices; M=2.78, SD=2.39, for innovation-oriented practices; z=-2.68, p < .01), the number of collaborators (M=7.00, SD=0.87, for efficiency-oriented practices; M=2.67, SD=2.40, for innovation-oriented practices; z=-2.54, p<.05), and the number of reads (M=82.67, SD=27.17, for efficiency-oriented practices; M=19.67, SD=17.05, for innovation-oriented practices; z=-2.67, p < .001). In the 2nd design cycle, as compared with the 1st design cycle, there were relatively less collaborative design efforts towards routinized practices and more collaborative design efforts towards adaptive practices, but the outcomes still remained quite the same that collaborative design efforts was more routine than adaptive, as indicated by the number of comments (M=9.44, SD=2.51, for efficiency-oriented practices; M=5.22, SD=2.95, for innovation-oriented practices; z=-2.14, p<.05), the number of collaborators (M=6.67, SD=1.66, for efficiency-oriented practices; M=4.33, SD=2.50, for innovation-oriented practices; z=-1.90, p=.058), and the number of reads (M=73.89, SD=20.26, for efficiency-oriented practices; M=40.78, SD=23.04, for innovation-oriented practices; z=-2.07, p < .05). In the 3rd design cycle, however, the difference of collaborative design efforts between the routine and adaptive teaching practices became much smaller; all statistics comparisons were insignificant as evidenced by the number of comments (M=6.56, SD=2.79, for efficiency-oriented practices; M=5.22, SD=3.38, for innovation-oriented practices; z=-1.01, p=.313), the number of collaborators (M=5.11, SD=1.90, for efficiency-oriented practices; M=4.22, SD=2.39, for innovation-oriented practices; z=-.71, p=.48), and the number of reads (M=45.67, SD=20.73, for efficiency-oriented practices; M=37.67, SD=25.35, for innovation-oriented practices; z=-.83, p=.41). The results suggest that progressively the participants were developing a more adaptive disposition towards their teaching practices.

The content of participants' feedbacks/co-design/reflection comments were further examined to explore how collaborative design efforts for improving efficiency-oriented or innovation-oriented teaching practices was qualitatively sustained over time. In terms of collaborative design efforts towards the efficiency-oriented teaching practices, for instance, the first inquiry thread in the figure (with 27 comments) was concerned with "control over lesson plan". In the 1st design cycle, it was found that the participants were highly concerned about how to implement their lesson plans efficiently. For example, as some participants suggested, "I realized that I should not spend too much time talking with students during my teaching practice so that I can more efficiently finish my planned teaching practice in time" (S6 in P3 or the 3rd practice); and "Based on my teaching plan, my teaching pace was too fast, so I need to slow down to better help students acquire the knowledge I want to teach" (S8 in P6). In the 2nd design cycle, the participants still paid much attention to whether they were teaching according to their lesson initially planned, even though there were relatively few feedbacks contributed. For example, some participants commented, "I need to be more consistent in my class management as I was always behind my teaching schedule" (S4 in P13), and "I need to carefully follow my lesson plan step by step to avoid unexpected interruption so that I can practice my teaching more as I planned" (S3 in P18). Moving towards the 3rd design cycle, the number of comments contributed to the "control over lesson plan" thread was greatly reduced and the comments also became less harsh; for example, "You may want to make sure there is still room to include additional learning activities in your lesson plan" (S1 in P21); and "You still need to work on time management, although you have done a good job to cover all the materials you planed to teach" (S9 in P24). These excerpts indicated that participants' collaborative design efforts towards teaching practice became progressively less routine oriented.

In contrast, participants' collaborative design efforts towards more innovation-oriented teaching practices were also qualitative changed over time. For example, in the inquiry thread titled "adaptability in teaching design" (which received 29 comments), it was found that the participants did not generate any comments or ideas that were suggestive of more adaptable teaching practices in the 1st design cycle. Not until the 2nd design cycle, did they begin to produce and share comments related to adaptive teaching. For instance, some participants commented: "If you can flexibly provide more time for students to take over their learning path, they will have different learning experiences and you will also learn how to teach in a less rigid manner" (S9 in P10); and "In my teaching practice in the second design cycle, I did not completely follow my teaching plan/script, but I tried to adapt my teaching methods based on how students responded to my instruction at the moment" (S8 in P13). Entering into the 3rd design cycle, it can be seen that participants' disposition towards innovation-oriented practices was even more obvious. For example, some participants commented, "You have been dedicated to improving your teaching skills, but since every teacher has different personality traits, I suggest that you think about how to adapt your teaching strategies by making good use of your personality strengths" (S1 in P22); and "You need to think about how to empathize with students in order to improvise their learning; the question is not how to teach, but to help students learn by using appropriate method at the right moment" (S6 in P25). These excerpts indicated a shift in collaborative design disposition towards progressively more innovation-oriented teaching practices.

An intended goal of this course was to engage students in collaborative lesson design work for teaching improvement. Therefore, it was posited that students would progressively become more comfortable working collaboratively in the Knowledge Forum. Overall, the increased online activities and enhanced social dynamics suggested that this is the case. Additional content analysis on the online feedback/co-design/reflection comments also suggested that the participants were able to progressively develop a more adaptive disposition towards mathematics teaching practices.

Regarding class teaching practices, first, over a school year, each student performed three teaching practices within three design cycles. So, in total, nine students performed 27 teaching practices. All 27 practices were video-taped and then uploaded online for peer feedback, co-design discussion, and self-reflection. Video analysis was conducted to examine changes in teaching practices. It was found that there was a progressive decrease in trend in terms of the percentage of time used for passive learning activities, with the activity time spent in the three practices being 72.0% (SD=17.4%), 46.8% (SD=19.5%), and 38.4% (SD=17.1%). In contrast, there was a progressive increase in trend in terms of the percentage of time allocated to active learning activities, with the activity time spent in the practices being 17.0% (SD=12.9%), 36.4% (SD=18.6%), and 41.9% (SD=13.8%). Moreover, it was found that there was a progressive increase in the practices being 10.0% (SD=14.0%), 16.2% (SD=13.3%), and 23.8% (SD=12.2%).

Concluding remark

As 'deep constructivism' (Scardamalia, 2002, p. 4), knowledge-building attempts to guide classroom activities away from proceduralized tasks to innovative knowledge work (Zhang, Hong, Scardamalia, Teo, & Morley, 2011).), Previous studies ranging from the elementary-school classroom setting to university context provided convincing examples of what students can achieve in knowledge-building classrooms in the advancement of

knowledge (e.g., see a special issue of the *Canadian Journal of Learning and Technology on knowledge-building*, Volume 36/1). In the present study, the findings further suggested that engaging teacher-education students in sustained knowledge-building in a teacher-education course could help the teacher-education students (a) learn to teach with progressively more adaptive manner, and (b) develop more adaptable practices. In conclusion, this study shows that the principle-based design approach was viable for guiding teacher-education students to develop more adaptive teaching practices.

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Connected Biology: A Usability Study of Web 2.0 Tools

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Abstract: We incorporated traditional conceptual knowledge in an introductory Biology course into a Web2.0 learning environment, which we called Connected Biology. We subsequently investigated whether faculty and students using it for 15 weeks found it useful. We used Crazy Egg (a commercial tracking site) to track students' use of Connected Biology and their use of Web 2.0 tools. Students found Connected Biology useful (learnable, memorable, satisfying, and error-free) but not efficient. Although they accessed Connected Biology over 15 weeks, they tended to use it primarily to get feedback on their understanding of course content and not for exploratory activities. Interviews with faculty teaching introductory science courses indicated that most hold to a prescriptive learning model. The paper argues that we need to attend to the prevailing culture of introductory science courses (both student and teacher) before introducing Web 2.0 tools. Only then will the affordances of Web 2.0 tools be attained.

Keywords: web 2.0 tools, usability, data-mining, data-tracking

Introduction

Steve Hargadon (2009) summarizes the belief held by many educators that the expectation that computers would revolutionize education has not happened. Computers have made the delivery and assessment of learning easier; but if they were suddenly to disappear from our classrooms, teaching would not change by much. One reason for this, somewhat surprising conclusion, is that until recently, the technology used, Web 1.0, used a traditional one-way information flow, with content flowing from the source (educational media and teacher) to the students. In other words, it used a "push" technology with information being "dumped" on the student according to the goals and scheduling constraints determined by the educator. However, this has radically changed with the development of Web 2.0 (Brown, 2006). Web 2.0 technologies facilitate conversations around academic concepts, artifacts (images and videos), and data collections (databases and spreadsheets) in which the "Three R's have been supplanted by the "Three C's: Contributing, Collaborating, Creating" (Hargadon (2009, p8) through tools such as Facebook, Twitter, Wiki's, Voicethreads, etc.

Canole and Alevizou (2010) conducted a literature review of the use of Web 2.0 tools in Higher Education using both traditional and Web 2.0 methodologies. That is, in addition to accessing the usual academic sources (peer-reviewed journals articles and books), specialized databases (ERIC, Informaworld, etc.) and GoogleScholar, they conducted an "open review" using the Cloudswork site (http://cloudworks.ac.uk/). They define the open review process as one that "uses a social networking space to aggregate and collectively discuss an evolving body of literature around a set of core research questions" (Canole & Alevizou, 2010 p 6). They found that despite the affordances of Web 2.0 tools to promote radical transformation of learning, most students use technology for convenience (51%) and to facilitate course management (19%). The effective adoption of Web 2.0 tools into education practice by teachers also requires a change in the role of teachers and teaching. Overall, "only a minority of teachers, those with a research interest in the learning sciences, educational technology, or new media, have undertaken experimentation with new innovations in pedagogy" (Carole & Alevizou, 2010, p21). They cproposed several paradoxes to explain the low adoption of Web 2.0 tools by post-secondary faculty. They may fear that the huge expansion of knowledge devalues expertise, that the fragmented, multi-located structure of networks destroys the integrity of domain knowledge structures, that the blurring of boundaries promotes plagerism, and that the social nature of learning networks harms individual learning at the expence of "group think".

Williams, Karousou, and Mackness (2011) contrast two learning environments: *emergent* and *prescriptive*. They associate the use of Web 2.0 tools with *emergent learning* networks and argue that both are required in an integrated learning ecology. The challenge becomes to design an effective balance between the two.

Many teachers, realizing the importance of incorporating active-learning participatory technologies into their teaching practices, do make the attempt; however, many, if not most, ultimately fail to sustain their efforts (Messina, Reeve & Scardamalia, 2003; Moreau, 2001). This has often been interpreted as a failure in their

knowledge, effort, or available resources. However, an alternative interpretation is that features of the attempted implementation, per se, are at fault. That is, although the utility of the implementation is usually investigated, the usability of the implementation was not systematically tested. Usability in this context, is the degree to which an implementation meets the needs of the users (both teachers and students) by being learnable, efficient, memorable, satisfying, and error-free (Usability Professionals Association, 2009).

The goal of this paper is to investigate the usability of an implementation, herein called *Connected Biology*, incorporating Web 2.0 features.

Methods

This project used the methodology of a design-based research (Brown, 1992; Amiel & Reeves, 2008), to investigate the usability and utility of *Connected Biology*. Thus, we used ethnographic, questionnaire, and tracking methodologies. More specifically, we interviewed teachers, assessd students' perception of the usability of *Connected Biology*, and useed Crazy Egg (https://www.crazyegg.com), a commercial tracking service similar to Google Analytics to track the number of visits and clicks made by students as well as where they clicke. Heat maps show where students stop scrolling and leave the page.

Participants

The participants were faculty and their students taking an introductory Biology course in a large urban community college. The students were 17-19 years old, in the pre-university science program, with an equal distribution of males and females (ie they're supposed to be digital natives.. Teachers were invited to participate in modifying and using *Connected Biology* in their courses.

Intervention

The intervention, *Connected Biology*, consisted of a web site which is acessed via a home page which includes a video, links to Science sites and an outline of the topics covered by the course. Each of the topics is linked to a topics page which includes the following elements: Pre-class Exercises (designed to prepare the students for the upcoming class), Classes (designed to outline the activities done in class), Consolidation exercises (designed to help students secure their learning), and the associated Learning Objectives (designed to guide students in their studying). The associated Web 2.0 tools associated with these elements are links to external sites, simulations, videos, images, a hot-linked glossary, on-line crossword puzzles, on-line concept mapping exercises, practice questions providing immediate feedback, links to on-line quizzes, and summaries of the content. Classes were held in an Active Learning Classroom, containing 6 tables, each with a Smartboard. There were 6-7 students per table. In addition, students used a class conference on First Class (a collaboration platform) to access their teacher's materials and communicate with each other and their teacher. The students were encouraged but not required to use any of these elements.

Analysis

Quantitative analysis

Questionnaires and tracking data were analyzed using descriptive and inferential statistics.

Qualitative analysis

Interviews with teachers were transcribed and coded into pre-existing categories that reflected the research interest.

Findings

Student survey of usability

We collected data on students' perception of the usability of *Connected Biology* after the unit on Cell Structure and Function, after the unit on Cell Division, and after the unit on Evolution. The maximum score on the survey was 25. Table 1 shows the changes in students' perception of usability over the three units.

There was a significant difference in students' perception of the usability of *Connected Biology* over the three sessions (F = 10.57 df = 3,119 p = 0.0001). Students rated the usability of *Connected Biology* lower for the unit on Cell Division (Mean = 16.0) than they did for the units on Cell Structure and Function (Mean = 18.1) and Evolution (Mean = 18.7).

Table 1: Descriptive statistics (mean and standard deviation) for students' perception of usability

	Cell Sti (N=		Cell Di (N=		Evolution (N=32)		
Usability	mean	sd	mean	sd	mean	sd	
Score	18.1	3.2	16.0	0.93	18.7	3.6	

The survey measured 5 aspects of usability; i.e., was the implementation Efficient, Free from Error, Learnable, Memorable, and Satisfying. Table 2 shows these aspects of usability over the three units.

Table 2:Descriptive statistics (means and standard deviation) for students' perception of aspects of usability.

Usability Aspect		ructure =32)		ivision =31)	Evolution (N=32)		
	mean	sd	mean	sd	mean	sd	
Efficient	3.6	0.82	2.9	0.43	3.3	0.93	
Error Free	3.4	0.64	3.1	0.49	3.7	0.68	
Learnable	3.9	0.81	3.3	0.35	4.0	0.85	
Memorable	3.9	0.84	3.1	0.28	4.1	0.94	
Satisfying	3.3	0.75	3.6	0.34	3.6	0.87	

There was a significant difference in students' perception of the efficiency (p = 0.002), freedom from errors (p = 0.002), learnability (p = 0.001) and memorability (p = 0.0001) of *Connected Biology* over the three sessions (F = 6.6 df = 10, 178 p = 0.0001). Students rated these aspects of the usability of *Connected Biology* lower for the unit on Cell Division than they did for the units on Cell Structure and Function and Evolution. Moreover, their responses on the usability for the unit on Cell Division were much more consistent (see Figure 1).

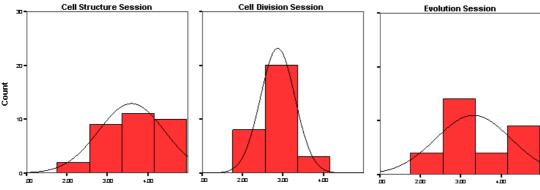
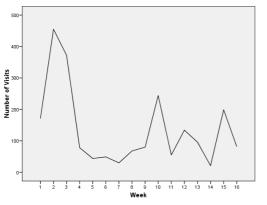


Figure 1. Distribution of students' responses to the efficiency of Connected Biology

Tracking of students use of *Connected Biology*

Students' visits, clicks, and scrolls were collected by Crazy Egg, a commercial tracking site (http://crazyegg.com). Figure 2 illustrates the number of visits to the home page of *Connected Biology* during the intervention.

Students visited *Connected Biology* between weeks 2 and 3, on week 12, and on week 15. There appears to be a novelty effect, in that students visited *Connected Biology* in large numbers at the beginning of the intervention; but less so as the semester progressed. Students may also have been tired at the end of the semester since their workload may have increased over the semester. The data suggests that students began to visit *Connected Biology* to prepare for the final exam on week 12 but stopped visiting it while they were preparing for their lab test and presentation of their research project (neither of which was covered by *Connected Biology*).



- Cell Structure was covered in weeks 1 and 2
- The first class test was given in week 3
- Cell Division was covered in weeks 4 and 5
- The second class test was given in week 10
- Evolution was covered in weeks 11 and 12
- The final exam was given in week 16

Figure 2. Number of visits to Connected Biology by week.

Figure 3 shows the number of visits to each topic over the semester. Students visited Cell Structure and Function when the topic was covered in class and the week prior to the final exam. On the other hand, students visited Cell Division when the topic was covered in class and the week of the second class test in which their understanding of this material was assessed. They also visited this topic, week 12, perhaps when they received the results of their second test after the Easter break (week 11). They did not visit this page to review prior to the final exam. Students visited Evolution when the topic was covered in class and to review for the final exam.

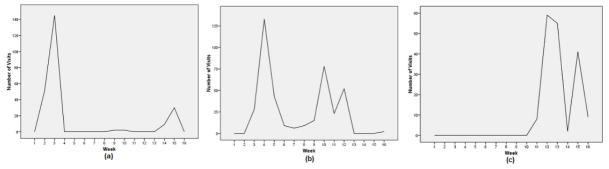


Figure 3. Number of visits to Cell Structure and Function (a), Cell Division (b) and Evolution (c) by week.

There were several elements across the three topics. Students' accessed *Connected Biology* via a home page which listed each topic and linked to topic pages for each unit. These topic pages included navigation links to preclass exercise, the classes, consolidation exercises, links to external tutorials, and activity frames with the objectives for each topic linked to a glossary. Each element had several Web 2.0 tools (e.g., on-line practice tests, immediate feedback questions, images/videos/animations, internal and external web activities, on-line crossword puzzles, on-line concept mapping activities, etc.).

Table 3 shows the number and percentage of visits to each element for each topic. The interactivity index (number of clicks/number of visits) for the Cell Structure and Function, Cell Division, and Evolution units were 0.96, 0.84, and 1.37 respectively. This indicates that students were using the topics page primarily to link to the elements. The students were surprisingly consistent in their visits to the elements. They rarely visited the linked tutorials (1.1%) which were featured on these pages.

	Cell Structure		Cell Division		Evolution		Total	
Element	N	%	Ν	%	Ν	%	N	%
Objective/Glossary	38	16	134	34.1	54	14.7	226	22.6
Link to Tutorials	6	2.5	2	0.5	3	0.8	11	1.1
Preclass Exercises	82	34.5	112	28.5	131	35.6	325	32.5
Classes	53	22.3	48	12.2	55	14.9	156	15.6
Consolidation Exercises	47	19.7	84	21.4	109	29.6	240	24.0
Navigation Buttons	12	5.0	13	3.3	16	4.3	41	4.1

Table 3: Number and student visits to Connected Biology elements.

How did students use the Objectives and Glossary Element

The interactivity indices (number of clicks/number of visits) were 0.1 and 0.3 for the Cell Structure and Function and Cell Division units, respectively. Students visited these elements primarily to review the learning objectives. In total they clicked on terms linking to the glossary 18% of the time.

How did students use the Pre Class Exercises Element

Table 4 shows the number and percentage of visits to each tool in the preclass exercises element for each topic. The interactivity index (number of clicks/number of visits) for the Cell Structure and Function, Cell Division, and Evolution units were 4.9, 7.7, and 12.2 respectively. Thus, students used this element to interact with the material. They also increased their interactivity over the span of the intervention. They were consistent in their use of the Web 2.0 tools, primarily using the Pre Class Exercises element to click on the immediate feedback questions (60.3%) and the summary of the topics (32.7%). They accessed the images, animations, and videos rarely (5.1%), and almost never accessed the suggested activities (1.2%).

Table 4: Number and	percentag	e of student visits to Web 2.0 tools in the Pre Class Exercises eleme	nt.

	Cell Structure		Cell Division		Evolution		Total	
Tools	Ν	%	Ν	%	Ν	%	Ν	%
Information	247	27.1	590	35.2	600	33.2	1437	32.7
Immediate Feedback	598	65.6	884	52.7	1166	64.5	2648	60.3
Questions								
Images/Animations/Videos	53	5.8	149	8.9	20	1.1	222	5.1
Activities	7	0.8	28	1.7	18	1.0	53	1.2
Navigation/Download	7	0.8	25	1.5	3	0.2	35	0.2
buttons								

How did students use the Class Element

We only collected data on how students used the Classes element for the Cell Structure and Function and Cell Division units. The interactivity indices were 0.4 and 1.6 respectively. Students visited these elements primarily to review the learning objectives. In total, they clicked on terms linking to the glossary 18% of the time.

How did students use the Consolidation Exercises

The interactivity index for the Cell Structure and Function, Cell Division, and Evolution units were 0.90, 0.80, and 0.65 respectively. Thus, students did not interact with this element. That is, they went to the page, read it, and left (using the back arrows). Table 5 shows the number and percentage of visits that students made to the tools on the consolidation element of the three topics. Thus, students used this element primarily to do practice quizzes on the topics. They rarely accessed the tutorials, and almost never accessed the on-line crossword or on-line concept mapping tools.

Table 5: Number and percentage of student visits to	Web 2.0 tools in the Consolidation Exercises element.

Tools	-	ell cture	Cell D	ivision	Evol	ution	Тс	otal
	Ν	%	N	%	Ν	%	Ν	%
Quizzes	91	98.9	116	93.5	7	100	214	96
On-line Crossword Puzzles	1	1.1	0		0	0	1	0.5
On-line Concept Map Tool	0		0		0	0	0	0
Link to Tutorials	0		8	6.5	0	0	8	3.5

Teacher views on integration of technology and Web 2.0 tools

Although 3 teachers (from a pool of 6 teachers teaching the Biology course) agreed to participate in the project, ultimately only 1 teacher did. Therefore, we could not conduct a usability study on teachers. Instead, we interviewed 5 teachers in order to understand the teacher culture that might prevent teachers from volunteering.

Teacher A believes that students need to see the relevance of the class content to their lives. He/ she spends a lot of time and resources collecting videos and research papers (suitable for students) and uses them in

class to initiate interest and discussion. Teacher A directs students on what sections of the textbook to cover and makes use of the on-line learning activities packaged with the textbook. However, he/she does not require students to do any of the activities because not all students have access.

Sometimes I bring in a YouTube documentary, but very short, and that starts the whole discussions. I think it gets them really stimulated when they see it. So I usually show them 5 minutes, and then that starts ... a discussion on that topic.

Teacher B believes that it is important to put together a perfect course (notes, learning objectives, quizzes, etc.) and make them available to students at the beginning. He/she focuses on the course content and on "figuring out" what and how to deliver it. Teacher B directs students to what material they need to know, what readings they should do (that will not be covered in class) and gives them some practice questions. He/she believes there is not enough time to cover all the content in class.

I am still trying to put together the perfect course, to master the information that I want to present, and ... how I want to present it. And have all of my course materials ready to go, learning objectives, practice questions and all that stuff.

I prepare [students] for the types of questions that I am going to ask them on class tests.

Teacher C focuses on the text book and he/she does not deviate from it. He/she uses the on-line materials (videos/activities/quizzes) packaged with the textbook in class because not all students have access to them. Teacher C allows students to bring their laptops to class and gives them questions/problems to discuss in small groups.

The textbook pretty much does [it] all, the online activity, it's because we mainly focus on the content of the textbook, so we don't really diverge ways from textbook. Like they can search on their own for some of our topics but I didn't encourage them.

Teacher D believes that students learn by doing and has designed activities for them to do in groups. He/she also believes that students need to be directed to the concepts they need to master, they need to come prepared to class, and need to consolidate their learning. Teacher D uses the teacher resources packaged with the textbook to design assessment questions at a higher cognitive level (analysis/synthesis). Teacher D focuses on how students are learning and what misconceptions they may have.

I've developed a lot of activities in class, educational activities, not just work sheets, but activities so that the students have to work together to do the research in the classroom to find, or discover the answer and then present it to the rest of the class.

[The website) is for pre-class preparation and post-class follow up, [for use] during the class, because there were links to videos, and other websites

Teacher E uses a suite of graded e-learning and problem-based learning activities which students complete as groups. He/she also uses a web-page that has instructional videos (from YouTube), practice questions, and the on-line materials packaged with the textbook to cover the course content.

We have a smart board [in the classroom] so I used that as a tool, and the way I used it, actually almost never pick up a real pen any more... so everything goes on the smart board, everything gets recorded, everything gets saved, everything gets then saved as a PDF, and everything gets posted for students to see. Then I created a ... website for one of my courses, I have videos for theory, solutions, I have some assessment question and I have real questions, sort of quiz type questions, with objectives. And that's my whole course covering every major topic in the course.

Conclusions and implications

Although most students found *Connected Biology* satisfying, learnable, memorable, and error-free (but not efficient), they did not make much use of the embedded Web 2.0 tools. That is, they used the web-site as an

electronic Study Guide. They used it when the topic was covered in class and prior to being tested on the content. They made little or no use of the enrichment tools (videos, activities, tutorials). Science students have a heavy workload, taking on average 3 science courses, a language course, a physical education course, a humanities course, and a complimentary course. They are very strategic in how they study. They made a great effort to complete the pre-class exercises, focusing on the acquisition of the content and testing their understanding. This had a positive effect on the class in that students came to class prepared. They were thus able to profit from the in-class activities and discussions. Thus, the prevalent student culture is: do the required work, participate in class, and prepare for tests. In other words they have a prescriptive model (Williams, Karousou, & Mackness, 2011) of learning biology where learning is predictable albeit complicated, the organization of knowledge is hierarchal, verification and correction is provided by the experts and not negotiable. This view may in fact reflect the reality of formal post-secondary science education, at least at the introductory level. That is, in most science domains knowledge is "created and applied to give control" (Williams, Karousou, & Mackness, 2011, p 43).

The teacher interviews also reveal a teacher-centered pedagogy in which most teachers "stuck" closely to the textbook and associated materials. For example, the common course outline specifies the pages in the text book that for which the students are responsible. All teachers, even those teachers that made use of Web 2.0 tools held a prescriptive learning model. This may reflect both the nature of science (as taught at the introductory level) and the assessment practices. Unless work is graded, students do not do the work. However, "the traditional interpretation [of assessment] becomes problematic [in emergent learning networks]" (Romer, 2002 quoted by Williams, Karousou, & Markess, 2011).

The Biology course is a multisection course with a common final which includes more than 85% multiple choice questions. This drives students to adopt a learning approach that discourages exploration and promotes focusing on practice questions. In addition, it discourages teachers from adopting more student-centered pedagogies. Given that this context is not likely to change, several questions arise: Is there a place for emergent learning in introductory science courses? If so, what is the optimal balance of emergent and prescriptive learning? Are there certain topics that are more suited to emergent learning and what are they? How do we "open up" assessment practices so that emergent learning is encouraged? How do we design emergent learning environments that are time-efficient for students? Many of these questions will have to be answered before the affordances of Web 2.0 tools can be realized in introductory science courses.

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A Multivocality Approach to Epistemic Agency in Collaborative Learning

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Abstract: The purpose of this study was to propose a multivocality approach to analyzing shared epistemic agency in collaborative learning and to test its effectiveness by examining actual datasets. We proposed the combination of social network analysis (SNA) and in-depth dialogical analysis as a multivocality approach and analyzed discourse transcriptions of collaborative reading comprehension by university students as datasets. First, we identified pivotal points of discourse where students might engage in an epistemic action toward alleviating a lack of knowledge. Then, we conducted in-depth analysis of discourse segments around the pivotal points. Results revealed that pivotal points identified by SNA were confirmed as alleviating lack of knowledge by further in-depth dialogical analysis. We further succeeded in identifying dialogical patterns in the shared epistemic agency and each individual student's contribution to them.

Keywords: shared epistemic agency, multivocality approach, social network analysis, in-depth dialogical analysis

Introduction

In the learning sciences, and particularly in the knowledge creation metaphor of learning (Paavola & Hakkarainen, 2005), intentional engagement by students in collaborative learning (including collaboration skills and intrinsic motivation) is discussed in terms of epistemic agency. In the metaphor of learning, students are expected to be involved in knowledge creation practice through collaborative construction of knowledge objects (Bereiter, 2002). In creating knowledge in the classroom, Scardamalia (2002) discussed the collective cognitive responsibility of students to contribute their ideas toward collective knowledge advancement. She defines intentional engagement by students in collective knowledge advancement as epistemic agency, and proposes this agency as a new goal of instruction in the knowledge age (Scardamalia, Bransford, Kozma, & Quellmalz, 2012). Based on the previous conceptualization of agency (Bandura, 2001; Emirbayer, & Mische, 1998; Palonen & Hakkarainen, 2000; Scardamalia, 2002; Schwartz & Okita, 2004; Stahl, 2006; Wertsch, Del Rio, & Alvarez, 1995), Dams a, Kirschner, Andriessen, Erkens, and Sins (2010) further propose shared epistemic agency as a new concept for identifying intentional student engagement in collaboration. Shared epistemic agency is a new layer beyond epistemic agency, comprising individual agency within collective activity, as proposed by Scardamalia (2002). Shared epistemic agency, then, focuses more on the group level of agency in collaboration (Stahl, 2006). Students in collaborative groups engage in the wholly joint epistemic actions of (1) being aware of their lack of knowledge, (2) alleviating this lack of knowledge, (3) creating shared understanding, and (4) generative collaboration. To regulate their joint epistemic actions, students also engage in (1) projection by setting goals and creating joint plans; (2) regulation by monitoring and reflecting on their own advancement; and (3) relation by transcending conflicts, redirecting critical feedback, and creating space for others' contributions. As agency in collaboration is multilayered, students should use both epistemic agency and shared epistemic agency when intentionally engaging in collaborative learning (Dams a, 2014).

An assessment approach for evaluating multilayered agency by learners has not yet been established. Because the agency in collaborative learning should appear at either the individual (Scardamalia, 2002) or group level (Damş a, 2014; Damş a et al., 2010) across different time scales, any single analytic approach would be unable to cover both. We plan to examine a new analytic approach to epistemic agency in collaborative learning from the perspective of the "productive multivocality approach" (Suthers, Lund, Rosé, Teplovs, & Law, 2013). The term "multivocality" is derived from a seminal work by Bakhtin (1981) discussing the presence of multiple "voices" in texts. The term refers to multiple voices of researchers who engage in the collective discourse of a field, such as the learning sciences. An assumption of the multivocality approach is that we can advance our knowledge in the learning sciences through the challenge of converting different epistemologies that usually make independent contributions into an interdisciplinary approach that is complementary in an integrative manner. In a book challenging this interdisciplinarity (Suthers et al., 2013), researchers from different

disciplines engage in productive discourse by analyzing shared datasets of social interaction in learning contexts from their own epistemological perspectives and methodologies.

One example dataset provided in this book was discourse among first-year university students engaging in collaborative problem solving in chemistry (Sawyer, Frey, & Brown, 2013a). From the results of an in-depth qualitative analysis, Sawyer, Frey, and Brown (2013b) concluded that two groups (Gillian vs. Matt) differed significantly in their strategic approaches. Based on conversation analysis of the two groups, Sawyer et al. (2013b) described profiles of the two groups. The Gillian group went beyond pure calculation by discussing conceptual ideas about what they had learned and engaged in collaborative knowledge construction through mutual reflection upon ideas. Conversely, the Matt group was involved in calculation activities without articulate recognition of what they had learned. In terms of shared epistemic agency, the Gillian group exerted their shared epistemic agency toward engagement in collective knowledge advancement. We (the first and the second authors in this paper) approached the same discourse dataset using a different methodology: social network analysis (SNA). The original discourse transcription was converted into a bipartite graph of vocabulary and conversation turns, and a temporal social network of vocabulary was constructed. By investigating temporal changes in several network indicators, we quantitatively identified pivotal points of discourse when students engaged in collective knowledge advancement. In addition, we further identified each individual agency by calculating individuals' contributions to the total social network (Oshima, Matsuzawa, Oshima, & Niihara, 2013). The interrelation between in-depth qualitative analysis and SNA was found to be complementary and productive. Both analyses provided unique and replicated findings. SNA demonstrates its analytic power when we are interested in a global view of discourse. We can create graphs of the transition of indicators as a discussion proceeds. After catching the global view of knowledge advancement, we can select several discourse segments to investigate more carefully. In this study, we used dialogical analysis (Wertsch, 1993) and SNA in a complementary and integrative manner to analyze epistemic agency at the individual and group levels.

The purpose of this study was to propose a multivocality approach to analyzing epistemic agency in collaborative learning and demonstrate how the proposed approach would actually function in an integrative manner. The context of learning of interest in this study was collaborative reading comprehension where university students collaboratively read articles to construct their conceptual understanding (a pedagogical approach to the learning environment) through jigsaw-based activities. Discourse transcriptions during the activity were analyzed by an integrative framework of SNA and in-depth dialogical analysis. The integrative analytic approach was focused on an action in shared epistemic agency, and particularly, alleviating a lack of knowledge. Alleviating a lack of knowledge is an important action for students in collaborative reading comprehension because students who read different articles attempt to co-construct their understanding by examining given sources (authors' arguments in the articles), collaboratively collecting new information to understand different authors' arguments, and structuring a new conceptual understanding to integrate arguments from different articles.

Methods

Collaborative reading comprehension was implemented as a part of an intensive course during the summer term of a teacher certification program at a Japanese public university. The course was run for four consecutive days, and the activity was conducted during the first day and a half. The second author was the instructor. Toward fulfilling the course requirements, eight third-year undergraduate students in the engineering department participated in this study. The goal of the course for students was to understand basic concepts of computer-supported collaborative learning (CSCL) in order to appropriately apply lesson plans. The goal for students in the collaborative reading comprehension was to understand basic principles of how to design learning environments (Bransford, Brown, & Cocking, 1999).

Collaborative reading comprehension

Collaborative reading comprehension is an activity structure designed based on the jigsaw method (Aronson & Patnoe, 2011; Brown & Campione, 1996). It encourages learners to engage in collaborative knowledge construction through building an understanding of multiple document resources (Figure 1). Students were first placed in expert groups after listening to an instructor's brief lecture on "the learning environment," which was the target concept. In each expert group, four students collaboratively read and constructed an understanding of one document, which they then explained to others in jigsaw groups. Through expert group collaboration, each student produced a summary by taking notes while listening to an audiobook on an iPod and discussing their ideas based on their notes. After the expert groups finished, jigsaw groups were formed; these groups consisted of one student from each expert group. Students in the jigsaw groups worked to integrate the ideas contained in the four different documents based on the student expert's explanations for each document. After discussing the

four documents, the students reported how ideas from the documents were related to one another and interpreted them with reference to the basic framework of learning environments in the Knowledge Forum CSCL system.

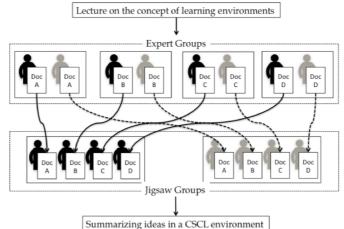


Figure 1. Participatory structure of collaborative reading comprehension

Documents used in the activity came from a book on how people learn in Japanese (Inagaki & Hatano, 1989). We selected four chapters of the book, covering four basic principles of learning environments: learnercentered, knowledge-centered, assessment-centered, and community-centered. Each chapter was transcribed to electronic form and reprinted as a standalone document. These documents were given as listening assignments to the expert groups, and we instructed students to take notes for organizing ideas from their document in relation to the learning environments concept. In jigsaw groups, students brought the ideas summarized from the documents on their note taking and discussed how the ideas from different documents could be integrated for advancing their understanding of the principles of learning environments. To facilitate the knowledge creation process, we further provided students with a whiteboard, on which a large Venn diagram of the learning environment was drawn, as well as sticky notes for inscribing and manipulating their ideas as knowledge objects on the shared space.

Multivocality analysis

As discussed in the previous section, we proposed a multivocality approach to analyze shared epistemic agency in collaborative reading comprehension by shedding light on alleviating a lack of knowledge. All discourse activities in expert and jigsaw groups were video-recorded and transcribed verbatim. We were particularly focused on discourse activities in the jigsaw group. Students engaged in discourse exchange 1,021 times in jigsaw group A and 921 times in jigsaw group B. One reason to pay attention to the jigsaw activity was that students were expected to actively engage in creating new ideas by integrating their knowledge from four different documents.

SNA for identifying pivotal points for alleviating lack of knowledge

For identifying pivotal points in discourse exchange for alleviating lack of knowledge, we conducted SNA by the following procedure. An assumption we held was that we would be able to represent collective knowledge advancement as structural change in a network of vocabulary that students used in their discourse. The vocabulary in this context refers to words used for representing argumentations in the documents students read. The structure of vocabulary refers to meaningful links between words in a sentence or an exchange. When students used words in their exchange, we assumed that they attempted to create meaningful links between words. In other words, we attempted to automatically create concept maps based on students' discourse data (although we could not correctly identify the meaning that students assigned to their links between words).

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Figure 2. Social network analysis with KBDeX

Based on this assumption, we first created a bipartite graph of words \times exchanges. The first author and a trained graduate student independently detected noun words that they thought represented authors' argumentations in the four documents. We used 305 noun words that both the author and graduate student detected for creating the bipartite graph. Then, we used an application called KBDeX (Oshima, Oshima, & Matsuzawa, 2012) to visualize a temporal network structure of vocabulary and calculate network indicators. KBDeX provides a temporal network visualization and automatically created graphs of network indicators (Figure 2). For identifying pivotal points, we paid attention to the temporal transition of a sum of degree centralities. The degree centrality is a measure of how many nodes are linked to a specific node ranging from 0 to 1. In other words, the degree centrality means how dense a network structure is. When we saw a remarkable increase in the sum of degree centralities of all nodes in a network from one exchange to another, we assumed that the latter exchange contributed to either making an existing network denser or restructuring an existing network by adding new words in such a way that a more robust structure was constructed. Thus, the increase in the sum of degree centralities may indicate that students in a group engaged in more robust ideas related to the original argumentations in the documents, a pivotal point in alleviating a lack of knowledge. In this study, we identified the pivotal points through visually inspecting transition of the sum of degree centrality coefficients and the individuals in a group who were involved in the pivotal points of exchanges.

In-depth dialogical analysis for revealing how students exerted their shared epistemic agency

Our SNA approach was hypothetical in nature and required complementary content analysis. Therefore, we also conducted in-depth dialogical analysis (Bakhtin, 1981; Wertsch, 1993) of discourse segments related to pivotal points identified in SNA. First, we detected sequences of discourse exchanges by tracing discourse back from corresponding pivotal points. Then, we evaluated whether automatically detected pivotal points were related to alleviating a lack of knowledge. Finally, if the sequences of discourse exchanges represented alleviating a lack of knowledge, we further analyzed how individual students in a group dialogically contributed to their shared epistemic agency.

Results

SNA for discourse transcriptions in collaborative reading comprehension

After reading transcriptions of discourse by two jigsaw groups (A and B), the first and third authors held discussions to divide the entire discourse into several discourse scenarios for each group. Here, a scenario refers to sequences of discourse exchanges in which students discussed ideas related to each other. For group A, the total discourse was segmented into three scenarios. Group B was segmented into two. Figures 3 and 4 demonstrate how the sum of degree centralities transited in scenarios by groups A and B, respectively. Circled discourse exchanges in each graph were identified as pivotal. By looking at the discourse exchanges around the pivotal points, we found that discourse exchanges identified were pivotal for alleviating a lack of knowledge.

Table 1 shows how many pivotal contributions each student had in discourse scenarios. In group A, student A1 was found to be a key contributor toward alleviating a lack of knowledge. In group B, on the other hand, key contributors in discourse were different across two scenarios. Students B2 and B4 had many contributions in the first scenario, but B1 and B2 had many contributions in the second scenario, when B4 missed the class.

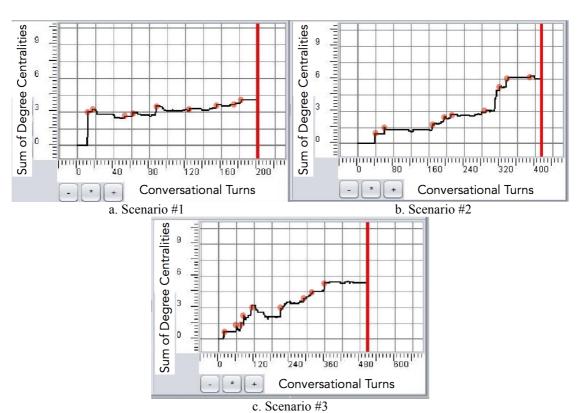


Figure 3. Transitional changes in the sum of degree centralities in discourse scenarios by jigsaw group A

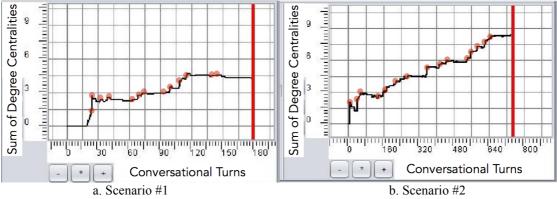


Figure 4. Transitional changes in the sum of degree centralities in discourse scenarios by jigsaw group B

		Jigsaw Group A	4		Jigsaw	Group B
	Scenario 1	Scenario 2	Scenario 3		Scenario 1	Scenario 2
Student A1	4	7	7	Student B1	1	9
Student A2	4	0	2	Student B2	5	6
Student A3	1	2	0	Student B3	2	0
Student A4	0	0	0	Student B4	5	Absent

Table 1. Frequencies of pivotal contributions by students

In-depth dialogical analysis of sequences of discourse exchanges related to pivotal points

After our SNA of discourse transcriptions, we further conducted in-depth analysis of discourse segments related to the pivotal points. Due to space limitations, we report one segment from each jigsaw group. The following is a segment of discourse from group A regarding the learner-centered design. The original discourse was in Japanese, and we have translated it into English.

Student A2:	It is not easy for learners to conduct intentional learning when their context does not support them. They need tools for engaging in intentional learning. So, we are discussing the context rather than the learners, aren't we?
Student A1:	But it is too simplistic to describe that this is entirely the issue of context because of the existence of tools for students.
Student A3:	We had better not say like "OK, this is an issue of context because of tools."
Student A1:	No, we should not. Yesterday, we discussed that the authors argued for the community-centered design when they described the context including others, tools, and so on because these factors facilitate students to intend to learn.
Student A3:	Yeah, we did.
Student A1:	We should not misunderstand the authors' argument. They did not argue that the context, such as others or tools, determines how students learn. In more precise terms, they argued that the context does facilitate how students intend to learn. These are remarkably different, aren't they?

In the discourse segment, the last discourse exchange by student A1 was identified as pivotal by SNA. In his last discourse exchange, student A1 alleviated a lack of knowledge about the learner-centered design and the community-centered design, and their interrelation as discussed in the documents. In the sequence of discourse exchanges, students A2 and A3 were found to engage in epistemic actions for student A1, who ultimately utilized his turn to facilitate their awareness of the problem (i.e., the first turn by student A2 and the third turn by student A3). In jigsaw group A, dialogues for exerting shared epistemic agency were represented by this example of discourse. Student A1 was responsible for ultimately promoting shared understanding towards alleviating their lack of knowledge, and other students (A2, A3, and A4) started sequences of discourse exchanges by creating awareness.

In jigsaw group B, we also found students' established dialogues for their shared epistemic agency towards alleviating a lack of knowledge. However, the dialogical practice in jigsaw group B was different from that in jigsaw group A.

Student B4:	B3, in what you said.
Student B3:	Yeah.
Student B4:	The authors proposed a variety of ideas related to different sections [in the Venn diagram of learning environment]. But all the ideas are related to the community-centered design.
Student B3:	In chapter 7, I read that the core concept was the community-centered design. All ideas are placed in intersections between the community-centered design and others.
Student B4:	I agree. I first did think that the community-centered design was independent of the three other designs. But, after your idea, I now think that those are overlapped like the Venn diagram. The community-centered design is related to all the others.
Student B2:	I also think so.
Student B4:	Age is also another factor for designing learning environments, I think. Depending the age of learners, we have to put different priority on the four designs. For younger kids, for instance, the knowledge-centered design does not seem to have much priority on designing learning.

In this discourse segment, the last discourse exchange by student B4 was identified as pivotal in SNA. Student B4 was engaged in integrating the other students' ideas to alleviate the preexisting lack of knowledge. The difference in dialogical patterns between the two jigsaw groups was that student B4 was also responsible for the awareness of the group's lack of knowledge. He intended to elicit others' ideas by revoicing others (i.e., the third discourse exchange). Other students (B3 and B2 in this discourse segment) were engaged in epistemic agency to provide additional information and examine B4's argument. This dialogical pattern was frequently seen in jigsaw group B to engage in their shared epistemic agency.

We accidentally found another pattern by group B. On the second day, when student B4 missed a class (scenario #2), other members were engaged in discourse holding different roles. The most remarkable result was that the role of student B1, who had not been active in scenario #1, changed to one of active engagement, identifying and alleviating the group's lack of knowledge by regulating other group members, just as student B4 had done in scenario #1.

Discussion

With discourse transcriptions as data, we conducted a multivocality approach to analyzing students' shared epistemic agency, specifically, toward alleviating a lack of knowledge. As a multivocality approach, we proposed a combination of SNA and in-depth dialogical analysis. In the following, we discuss the potential productivity of this approach.

SNA can be used for numerically identifying pivotal points of the alleviation of a lack of knowledge as well as the creation of awareness. The rapid increase in the sum of degree centrality coefficients of nodes was confirmed as a vital sign for collective knowledge creation. Dialogical analysis of discourse segments around pivotal points in SNA suggested that we could numerically identify how students engaged in the particular actions of shared epistemic agency. However, there might be pivotal points of discourse exchanges that we could not address by SNA. To test this, we must conduct in-depth dialogical analysis for all the transcriptions and compare results between the dialogical analysis and SNA.

We also examined each individual's contribution by counting and comparing numbers of pivotal points by different students. On the contrary to our naive prediction of egalitarian contribution, we found idiosyncratic contribution patterns. Some students made more contributions than others. In group A, one student was mostly responsible for the agency, whereas several students had critical contributions in group B. As discussed in the next paragraph, however, these patterns of social interaction were rather productive practices where students engaged in shared epistemic agency in a variety of ways.

Complementary in-depth dialogical analysis provided us with rich information for clarifying how students engage in their epistemic actions toward alleviating a lack of knowledge. The pattern of each individual's contribution was found to be stable, indicating that students might have their cultural epistemic practices established through their experiences of being together across several courses before taking this course. In group A, students more collaboratively regulated their agency, whereas specific students in jigsaw group B (B4 and B1) were dominant. It was also found that students' epistemic practices were resilient to unpredictable events. Even when a dominant student (B4) was not present, remaining students in jigsaw group B could maintain their epistemic practice through different contribution patterns (student B1, who had been inactive in scenario #1, took over the regulation of the epistemic actions of the group).

Conclusions

In summary, the multivocality approach combining SNA and in-depth dialogical analysis to shared epistemic agency in collaborative learning was found to be productive in that SNA presented a macroscopic view of how students in groups engage in epistemic actions to create their new knowledge. On the other hand, in-depth analysis of discourse segments identified as pivotal by SNA provides a more microscopic view of group cognition (Stahl, 2006). This study dealt with small datasets of just two groups in collaborative reading comprehension. For further testing the reliability of the combination of SNA and in-depth dialogical analysis of shared epistemic agency, we need to conduct future studies (1) to deal with larger-sized datasets and (2) to analyze different epistemic actions.

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"This Is the Size of One Meter": Children's Bodily-Material Collaboration and Understanding of Scale around Touchscreens

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Abstract: In CSCL studies, language is often foregrounded as the primary resource for engaging in collaborative learning, while the body is more often positioned as a secondary resource. In this paper, we present, analyse and discuss how two nine-year-old children collaborate through gesturing and moving their bodies around a touchscreen. The pair is working with the concept of scale and are in midst of copying their rooms from paper to touchscreen. During this process, the pair engages in a discussion regarding the size of one meter through language, gestures and manipulation of the material resource. The analysis shows two distinct ways of understanding the length of one meter, which primarily is visible through the children's gesturing and bodily movement. In conclusion, the analysis shows that children dynamically produce body-material resources for communicative and illustrative purposes; moreover, they use body-material as a cognitive tool and as a way of shepherding the other.

Keywords: touchscreens, embodied interaction, knowledge building, video analysis

"When the proportions of architectural composition are applied to a particular building, the two-termed relationship of the parts to the whole must be harmonized with a third term—the observer. He not only sees the proportions of a door and their relationship to those of a wall (as he would in a drawing of the building), but he measures them against his own dimensions. This threetermed relationship is called scale." (Britannica Online Encyclopedia, 2014).

Introduction

While already Vygotsky (1986) argued that gestures and body movements play a central role in children's communication and learning it seems equally evident that even in Vygotsky's own work language is considered the main vehicle for learning, communication and collaboration. Likewise, within CSCL, we would argue, language and tools (artifacts) have been considered the most important resources to study. We certainly do not wish to dispute the central role of language and artifacts, but we would like to emphasise the role of gestures and body movements as bodily-material resources which are also important in relation to communication, learning and collaboration. In this paper we present, analyse and discuss a short video excerpt (36 seconds) of two nine-year-old children's interaction and collaboration around a touchscreen. The excerpt is a small clip from a larger set of data (video, interviews, and observations) from a long-term research process and collaboration with a particular school over an entire school year. While we return to the context of the data the main purpose of this paper is to use a small example to illustrate the richness and complexity of the bodily-material resources in play in children's collaboration around touchscreens. Within this short duration of time we discuss how bodies and gestures are used as both communicative/illustrative, cognitive and collaborative resources, and we show how they are dynamically used to organise intra- and inter-psychological processes. In the example the children are working with 'scale' and we trace how they use both language and gestures to convey and negotiate their understandings of this concept. We argue that they use the bodily-material resources as 1) a communicative and illustrative resource for showing each other their understandings, 2) a cognitive auxiliary tool scaffolding knowledge building, and 3) a way of shepherding (Cekaite, 2010) and instructing each other. Further, we discuss how we view this as particular relevant to the (re)growing interest in co-located collaborative environments (Higgins, Mercier, Burd, & Joyce-Gibbons, 2011) within CSCL and how it adds to our current understanding of learning and collaboration. In brief, the interest in co-located collaborative settings has been instigated by the technological development of various multi-user technologies, such as tabletops and interactive whiteboards. Among other things, the possibility for several users to touch and manipulate objects on the screen simultaneously has been highlighted as a major benefit for collaborative learning. While researchers often emphasise that the possibility to touch is more direct than interaction through keyboard and mouse, we take the stance that the zone in-between children and touchscreen afford new conditions for children's bodilymaterial communication, collaboration and learning.

Theoretical and methodological orientation

In CSCL, language (written text and spoken utterances) and artifacts are viewed as the primary resources for engaging in collaborative learning activities online, face-to-face or in blended learning environments. Stahl argued that "*meaning is created across the utterances of different people*" (2006, p. 6 italics in original), and in a recent overview of CSCL Dillenbourg, Järvelä and Fischer (2009) stated that language is believed to be the primary resource for engaging in collaboration. Text (like other physical objects) is also considered as an artifact in the CSCL community, which can embody meaning or facilitate intersubjective processes of meaning-making (Stahl, 2006). CSCL has developed methodological and theoretical rich vocabularies for analysing and discussing the role of language in collaborative learning. Nevertheless, a group of CSCL researchers have argued that gesturing and body movements equally play a central role in establishing and negotiating shared understandings of problems (Davidsen, 2014; Greiffenhagen, 2011; Lymer, Ivarsson, & Lindwall, 2009; Roschelle & Teasley, 1995). Bonderup-Dohn (2009), taking a phenomenological stance on CSCL, argued that interaction should be viewed as a bodily phenomenon, yet, Bonderup-Dohn only provided a theoretical understanding of the body's interactional and cognitive potential. Likewise, Ingold (2014) eminently formulated the role hands in human interaction in a recent talk; "hands are the means of togetherness that is they are instruments of sociality".

In order to analyse how children use their hands and bodies to as resources for engaging in collaborative learning, we have applied embodied interaction analysis (Streeck, Goodwin, & LeBaron, 2011) to a short video excerpt. Rather than assuming language as the primary resource for collaborative learning, embodied interaction analysis focus on a triad of constituting semiotic resources; language, body and material. We use the video excerpt as an illustration of the importance of understanding children's gesturing and bodily collaboration around touchscreens – in the zone in-between, which opens a window to understanding children's embodied (bodily-material) methods of communication, collaboration and learning, e.g. how they use their hands and bodies as a means of producing situated understandings and as a means of thinking together around touchscreens.

Related work

Within the past 15 years, the CSCL community has been active in designing for and understanding collaborative learning around multi-user technologies, like tabletops and interactive whiteboards. This forms part of what Higgins, Mecier, Burd and Hatch (2011) characterised as a reorientation to collaborative learning in co-located settings. The various studies on tabletops revolve around one of the basic research traditions identified by Stahl, Koschmann and Suthers (2006); namely experimental laboratory studies. In this paper, we briefly examine the experimental studies to review some findings, methods and theories found in the body of related studies on collaborative learning around touch technologies in order to situate our work within the tradition of CSCL research.

Some of the general traits of the experimental studies are; laboratory settings, restricted/limited time frames, selected user groups and hypothesis testing. Some of these laboratory experiments have provided important findings on children's collaboration around tabletops; for instance, Harris et al. (2009) reported that children talked more about turn taking using single-touchscreen and that children were more task oriented in a multi-touch setting. While Rick, Marshall and Yuill (2011) suggested that enforcing equitable physical participation can disrupt the dynamics of collaborative learning. Finally, Higgins, Mercier, Burd and Hatch (2011) stated that multi-touch tables support collaborative interaction more effectively than the paper-based version of the task. Another common characteristic of the experimental studies is the methodological orientation towards coding and counting children's interaction by applying different theoretical models. For example, Mercier and Higgins (2014) applied two coding schemes; one for determining levels of reasoning and one for determining tabletop use (direct touches on the surface). By separating levels of reasoning and tabletop use, however, Mercier and Higgins enforced a split between language and body movement. The separation of language and movement might be a fruitful analytic distinction, but, as we shall show in the analysis, this can potentially leave out subtle details of the interconnections between thought, language and bodily-material resources in children's joint reasoning and collaboration. As observed by Vygotsky "Communication without action remains unintelligible (...)" (1986, pp. 52-53) for the child, and we suggest that these relations are important to scrutinize more carefully. Furthermore, we also argue that although 'direct touches' on the touchscreens are obviously important, it is equally important to understand bodily interaction and gesturing in the zones in-between the touchscreens and the children. As we will show this zone is important in terms of communication, collaboration and learning.

The "Move and Learn" project: Two children working with the concept of scale

The "Move and Learn" project was a technology integration project initiated by a Danish public school where two classrooms were physically re-organised with 16 single-touch screens and two interactive whiteboards. The school invited researchers (one being the first author) to follow the process. Throughout a year two researchers followed and worked with the school (Davidsen & Georgsen, 2010) and collected data in a variety of ways (e.g. 150 hours video material, observations, interviews, and screen-recordings). In the example we present and analyse, the children and teachers (1) had been working with the single touchscreens in their classrooms for about nine months and therefore had some experience in working together with the touchscreens.

The example stems from the final period of the "Move and Learn" project and the teacher had designed learning materials where the children were to collaborate on an assignment regarding the concept of scale (see Figure 1). As a final outcome of the children's work with the concept of scale they were to produce a multimodal story about their own room at home illustrating also their understandings of the concept of scale. The task involved two overall steps. First each child had to measure and draw their room on traditional squared paper. Second they had to draw their rooms together with a classmate using the touchscreen. While sitting together, the children had to go through three steps (see Figure 1): 1) Draw their respective rooms on the touchscreen together, 2) position the relevant objects (provided by the teacher) in the room and 3) finally record a multimodal story about their own room. Hence, the learning material designed by the teacher serves as an action- and information-space for the children (Figure 1). The design of the tasks did not prescribe how to collaborate. Hence, the children had to negotiate how to collaborate. While the task of converting their drawings from paper to screen was 'just' copying from one medium to another the children's translations from paper to touchscreen provide a demonstration of their individual understandings of scale and size of one meter.

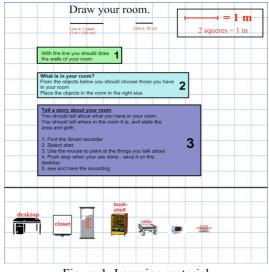


Figure 1. Learning material

Distributed over a week the children worked with the task in 5 sessions of 45 minutes. In total, 11 hours and 17 minutes of video footage were recorded with three different pairs working with this learning material. On this basis, we selected one situation (36 seconds) to illustrate how the children use bodily-material resources for communication, collaboration and learning. In the example we follow Natalie and Peter. Similar to the rest of the pairs in the classroom they have been working with the overall task for one week, and in the particular situation they are in the midst of transferring Natalie's room from paper to screen. The situation was transcribed using TRANSANA and ELAN.

Children demonstrating their understandings of one meter and the concept of scale

Below, in Figure 2 and 3, the chronological development of the children's activity is represented with transcripts and "pencil drawings" based on the original video footage. With the situation we want to illustrate different aspects of the children's ways of using gestures and movements, e.g. as a communicative and illustrative resource, as a cognitive tool and as a way of shepherding and instructing each other. Following the presentation of the children's activity, we analyse and discuss the findings in relation to CSCL on a theoretical and methodological level. The children's talk is either above the or next to the numbered pencils drawings. In our descriptions, we will be referring to the numbered drawings and talk as frame 1-14.

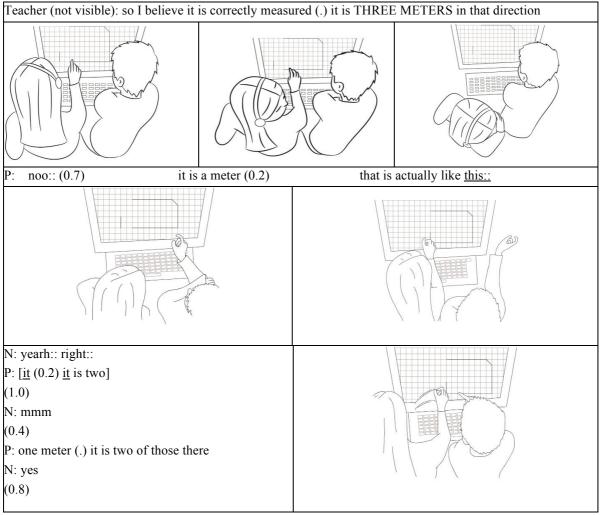


Figure 2. Transcript part 1

At the outset of this situation, Nathalie is about to place the vertical line in connection to the horizontal line. She attempts to drag the line, however, the line does not follow, - in the same moment and movement she turns her torso and head right, looking away from the touchscreen and out into the classroom (attending possibly to the teacher saying out loud 'so I believe it is correctly measured (.) it is THREE METERS in that direction') - (frame 1-3). While doing so, Nathalie retracts her right hand from the touchscreen. In making her new body position, Nathalie does not finish her work on the touchscreen and the vertical line (wall) on the touchscreen remains in the same place. This serves as the basis for Peter's evaluation of her work (frame 4-5). Nathalie returns to her original body position (frame 4-5), and while Peter is evaluating her misplacement she stretches forth her right arm and begin to move the vertical line towards the correct position. Simultaneously, Peter stretches out his right arm and says 'noo:: (0.7) it is a meter (0.2) that is actually like this::' (frame 4-5) and shows his understanding of one meter with a gesture, e.g. the relation between two squares on the touchscreen by positioning his thumb and index finger as a way of indicating approximately one meter (two squares). At first Peter was gesturing in front of the touchscreen (frame 4); however, when Nathalie approached the touchscreen Peter smoothly moved his hand away from the screen to the right (frame 5). Peter maintains his gesture next to the touchscreen while Nathalie is correcting her misplacement. However, when Peter is saying 'that is actually like this::' and holding his gesture for 1.5 seconds, Nathalie looks briefly in the direction of his hand, but keeps moving the line. In frame (6) Peter keeps explaining his understanding of a meter, now shifting his gesture to pointing sequentially at two adjacent squares while saying 'one meter (.) it is two of those there'. All along Natalie is agreeing through verbal feedback (yearh :: right ::, mmm, yes) while simultaneously moving the line, which is in the correct position as Peter says 'it (0.2) it is two'(however, she keeps fiddling with it until frame (7)). As a response to Peter's final comment 'it is two of those there' (frame 6), Nathalie agrees again with a

'yes'. In frame (7) Peter keeps explaining, but Natalie takes over the turn by raising her voice saying '[AND THAT] is why I say:' and she starts counting the length of the horizontal line using her index and middle finger.

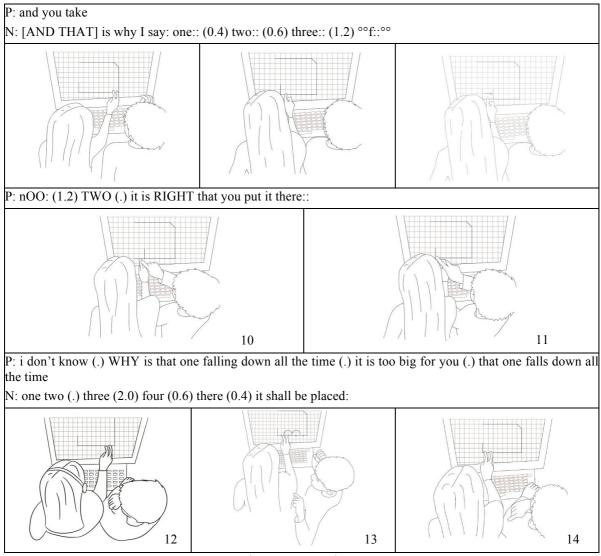


Figure 3. Transcript part 2

From the transcript (frame 7-8), it is visible that Nathalie hesitates between three and four, and her fingers end up six squares into the line, rather than eight. While she is demonstrating her understanding and rationale to herself and Peter, she notices that something is not in order. Then she decides to move the vertical line from the correct position to a position two squares to the right (frame 9). The actual length of the line is now three meters instead of four. Peter evaluates Nathalie's work once again (Figure 7) saying 'nOO: (1.2) TWO (.) it is RIGHT that you put it there::' and then he moves his right hand close to Nathalie's (frame 10-11). Now Peter is shepherding (Cekaite, 2010) Nathalie's hand from the sixth square to the eight square. Compared to Peter's first evaluation, where he showed Nathalie his understanding of one meter with a gesture, he now moves his right hand close to Nathalie's hand and shepherd her hand to the correct position. However, Peter only shows Nathalie the right place of the vertical line and while he retracts his hand Nathalie moves her hand to the right and touches the vertical line and then moves it to the correct place.

After Nathalie places the vertical line in the correct place, the children start orienting themselves to two different things (frame 12-14); Peter starts paying attention to Nathalie's clothes as her blouse strap is falling down from her shoulder whereas Nathalie maintains her focus on the placement of the vertical line. While Peter is commenting on Nathalie's clothes, Nathalie starts to recount the length of the horizontal line by tapping on it with her gesture (index and middle finger). Nathalie is counting by nodding her head, moving her lips and

pointing to the squares on the touchscreen. In this situation, she is gesturing for herself, and trying to confirm that she placed the vertical line in the correct position, while Peter is oriented towards her blouse strap. She restarts her counting twice, possibly because being distracted by Peter commenting on the strap. The activity ends after Nathalie has attempted to count the line three times and finally reaches the end of the line saying and reconfirming 'there (0.4) it shall be placed'.

Discussion

It should be clear from the preceding section that gestures, body-positions and body-movements or what we term bodily-material resources play a central role in coordinating the children's interaction and collaboration (as does language of course). It seems that there is a closely knitted mesh between the bodily-material resources and language in these situations. There are no signs of language being more important for their coordination than the body-material resources, and much of the interaction would not be intelligible if we looked only at the utterances. This, however, is often the case in human interaction around artifacts, but as we shall argue the role of the bodily-material extends beyond interaction and communication. In the following we therefore "zoom out" slightly and offer a more analytic and interpretative perspective on their interaction and the relations between collaboration, learning and bodily-material resources. As mentioned initially, we see three distinctive ways of using bodily-material resources: 1) as a communicative and illustrative resource for showing each other their understandings, 2) as a cognitive auxiliary tool scaffolding knowledge building, and 3) as a way of shepherding (Cekaite, 2010) each other.

Bodily-material resources for communication and illustration

Throughout the activity, Nathalie and Peter move their hands and body to communicate and illustrate their understandings of scale and one meter, as well as to coordinate their work. For example, Peter produces a gesture (frame 4-5) to communicate his understanding of one meter to Nathalie – and seemingly not aware she is correcting her misplacement or unsure of her reception of his intentions he also points to the screen while saying 'two of those there' to emphasise that one meter is equal to two squares. Natalie does something similar immediately after where she says 'Yes, and that is why I say, one, two, three' and she starts to illustrate, how she has come to the same conclusion (frame 7-8). It is equally interesting how they mobilise their bodies as part of the work. In this particular example their movements are in sync and they follow each other like dance partners. This is difficult to convey in the transcripts, but in frame 4-5 where Nathalie returns to the screen her arm comes in over Peter's head and he, with an elegant sway, moves his hand to allow her room. Likewise, though they are seated quite close, they don't bump into each other or seem to be fighting over the space. Rather they leave room for each other (particularly Peter). This, however, when looking more broadly at the collected data material is not always the case. In fact, Peter appears in another analysis (Davidsen & Georgsen, 2010) at an earlier period in the project. In that situation he collaborates with another girl, where they physically push each other's hands and bodies away as to gain screen-control. Thus, and particularly perhaps for children collaborating around shared artifacts, coordination and collaboration concerns not only the verbal interaction and 'turn-taking', but equally bodily-material cacophonic or harmonic 'dances' between the participants.

Bodily-material resources for cognition

While the use of bodily-material resources for communication and illustration is prevalent throughout the activity, the gestures, we argue, also serve other means; namely as cognitive auxiliary tools (Vygotsky, 1986). Peter's gesture using thumb and index finger to approximate what 'a meter is' on the screen can be seen as such a cognitive auxiliary tool. However, this is most prominently displayed by Nathalie's two-finger counting system where she uses her index and middle finger to count. We interpret it as both a spatial, as well as numerical tool - spatially her two fingers occupy (if held correctly) the same space as two squares, and simultaneously the 'two' fingers can serve as a numerical reminder that it is 'two squares' that equals one meter (on the day before she does count four squares and assume that to be four meters, but is corrected by Peter). In this sense it can be interpreted as a specialised or custom-made tool that orients to or is conditioned by the particular design for learning (the work space provided by the teacher). Hence, Nathalie and Peter are using their hands in mobilizing and producing new (though ephemeral) semiotic resources (Goodwin, 2000) through their distinct ways of gesturing (or perhaps re-iterating or repurposing gestures that have been employed in similar situations). As can be seen from their interactions these tools are both 'personal' (they use different gestures), but also 'public' i.e. communicative/illustrative. In fact, in the first instance where Nathalie starts counting and makes an error causing her to misplace the vertical line (although she placed it correctly) could be interpreted as a transformation happening midways in-action from public, illustrative tools towards personal, cognitive tools. She initiates the turn by saying "Yes, and that is why I say" and starts visualising to Peter her

line of reasoning, and how she arrived at the placement. It, however, results in an error, as she seems to be illustrating more than really 'counting' i.e. it seems a more outward-oriented action. In contrast when she, shortly after, returns to re-count, it is done as what seems a more 'inward-oriented' activity. She is nodding her head simultaneously and moving her lips with no sound, and re-starting the count twice as perhaps disturbed by Peter's attention shift towards her blouse strap. In addition, their various gestures also demonstrate that they seem to have understood the notion of scale, and that 'something else' can represent one meter in their actual room, and that these relations can be expressed in a number of ways: squares on paper, on a screen, as an approximated gesture (Peter's thumb and index finger), tapping two squares or Natalie's middle-index finger 'counting device'. In fact, in the short clip, there are a number of different 'meters' present in different modalities that they seem to shift more or less seamlessly between.

Bodily-material resources for shepherding

Whereas we see a couple of situations where the children use bodily-material resources for communicative/illustrative purposes and as cognitive auxiliary tools, we only see one situation where their bodily-material resources are used as a way of shepherding or instructing the other. In frame 10-11, Peter is saying 'nOO: (1.2) TWO (.) it is RIGHT that you put it there::' and moving his right hand towards Nathalie's and together they move their hands left, right above the correct position of the vertical line. This particular moment, movement and touch shows how hands and language mutually constitute each other, and particularly how hands can be used as a resource for shepherding the other. Nathalie, then, swiftly moves her hand away from Peters and moves the vertical line to the correct place. He is showing her the right place, while she is moving herself and the vertical line to that place afterwards. In a way this movement seems to extend our discussion of their bodily conduct. There are different ways of bodily intervening with each other's space (and limbs), and that this might also form part of what a fruitful collaboration is or can be.

Embodied interaction in the zone in-between

Having presented, analysed and discussed the children's use of body-material resources for communication, collaboration and learning; we would furthermore emphasise that the space in-between children and the touchscreen serve as an important space for these processes to unfold. Thus, we suggest that what take place in-between the children and the touchscreen is of crucial importance when trying to understand children's collaborative activities in such a setting. While, it is obviously useful to look at the direct interaction with the screens, we would argue that there are two other kinds of interaction that are of interest. For one thing, we have pointed out that much of their coordination, communication and collaboration is sustained by movements, touches and gestures not directly interacting with the screen, but rather is performed in the open space inbetween (space between the screens and the children, but also the space in-between the children). Secondly, we would point to what we could call in-direct interaction or simulation of touch. These are points in time where they are not actually touching the screens, but 'hovering' in front of the screen (as Natalie is counting or Peter tapping/pointing to squares). Thus, if we rely mainly on analysing the moments where they physically touch the screens (as this is recorded by the software) we should be conscious of what we might be missing. We therefore suggest that including the zone in-between can provide a more holistic understanding of communication, collaboration and learning around touchscreens.

Conclusion

Our main purpose in this paper has been to illustrate that bodily-material resources are important in relation to understanding CSCL, and particularly of course the notions of collaboration and learning. By presenting the situation with Nathalie and Peter we have provided a glimpse of their methods of engaging in collaboration around touchscreens through language and body-material resources. The children's language, gesturing and movement serve as resources for their individual and shared emergent understanding of 'scale' and the length of one meter, e.g. they are using their hands to produce situated understandings (Streeck, Goodwin & LeBaron, 2011) and as a means of building knowledge together (Stahl, 2006). As we have shown, a heightened analytic sensitivity towards bodily-material resources can uncover some perhaps otherwise unnoticed and subtle details of collaborative learning. While we have provided insights on the role of bodily-material resources in collaborative activities around touchscreens, we have also experienced some difficulties of making visible the dynamic and simultaneous gesturing and movement. Hence, there seems to be a potential for CSCL researchers to understand the dynamic simultaneous unfolding of embodied interaction to advance theory and method of the research field. For example, it could be interesting exploring in a more longitudinal perspective the genesis and development of Natalie's two-finger gesture. How does this emerge, do others adopt a similar practice or is she adopting it from someone else (e.g. the teacher). How does their bodily conduct develop over time, can we trace

changes in the way they occupy or intervene in each other's space, and what would this tell us about developing collaboration 'skills'. A deep and detailed focus on such short-lived moments of interaction can help us understand otherwise unnoticed subtleties and details of collaboration and learning, while a coupling with a more longitudinal perspective can help us trace the development or the longer-term influences on learning.

Endnotes

(1) Names of each child, teacher and the school have been changed to secure their identity.

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The Development of Situational-Misconceptions in Math Problem Solving

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Abstract: In this paper I use the *conceptual change* theoretical framework, in order to describe and evaluate the productivity of teacher's in-situ support to *Situational misconceptions*. I illustrate a case in which two students work together in order to solve a problem in math. The focal point is their teacher's intervention, in which she attempts to get her students out of a messy situation. This analysis helps to understand, in fine grain, the process – and consequences – of avoiding refutation of non-productive narratives, before adding new ones - in the context of math problem solving. In addition, we learn that in the process of solution, narratives might not always compete: ideas from two, or more, narratives could be forged to new *Situational misconceptions*.

Keywords: Conceptual-Change, Situational-Misconception, Math Problem-Solving, Competing Narratives

Introduction

Misconceptions could be best described as "*qualitative incorrect explanations* that are expressed prior to, and even after, formal instruction" (Chi, 2012). These incorrect explanations are outcomes of naïve theories that are developed and retained; theories that are many times consistent with the information that one has about the phenomena at hand, and thus, seem coherent to him (Vosniadou and Verschaffel, 2004). This notion of coherence will not disappear easily - causing meaningful change of some misconceptions is quite difficult (diSessa, 2006).

Studies about *misconceptions* could be allocated to three theoretical frameworks, (diSessa, 2006). One line of work, claims that there are sporadic concepts that appear in various domains of knowledge, mainly scientific in nature, such as Physics, Biology etc. These misconceptions should be mapped and treated specifically, in order to preform *conceptual change* (diSessa, 2006). The other two lines of work adopt Kuhn's *Paradigm change* theoretical framework. Accordingly, research about misconceptions in these lines of work, focus on the gap between misconceptions and the appropriate "scientific explanation". This gap is illustrated by Carey (1988) as a mechanism that restricts *conceptual change* due to incommensurability between competing mental models. This incommensurability restricts the building of the intersubjectivity that is needed in order to form productive discourse which builds common knowledge, but also help to refute non-productive ideas (Matusov, 1996). If we look at it the other way around, awareness of an incommensurability might trigger the need to come to shared understanding, through the process of collaborative meaning making (Stahl, 2009). This leaves us with the question: what are the traits of productive conceptual change? In particular, how could manifestations of incommensurability overcome?

Several solutions has been provided in the literature. The origins of most of these approaches is the elicitation of cognitive conflict (e.g von Glasersfeld 1995) between the current mental model and a new mental model. Chi (2012) for example, suggest that the solution is in a meta-strategic level: teaching students to be aware of competing narratives to approach the explanation of a phenomena, will lead to the realization of a new – maybe incommensurable – explanation. These explanations could be critically evaluated and compared; eventually, and hopefully, lead to the conceptual change. The same dialectical principle - meeting competing narratives – is applied with *refutation text*. A meta-analysis about *refutation text* by Tippett (2010), reveals that conceptual change could be achieved when the text (1) Starts with a description of the phenomena, (2) explains the misconception, (3) refutes the misconceived explanation, and finally (4) provides a new explanation that makes sense to the learner. In congruence, Asterhan & Schwarz (2007) show that engaging in argumentative discussion helps overcoming misconceptions; thus intelligible discussion about competing narratives/mental-models, could lead to productive refutation of the "wrong" and learning the "right". This same principle was described in the context of math, as Schwarz, Neuman and Biezuner (2000) show how argumentative scheme positively affects change of the use of decimal numeral systems.

Math problem solving and conceptual change

Math learning-and-instruction might benefit from adopting conceptual change models (Vosniadou and Verschaffel, 2004), since learning math often requires meeting competing narratives and choosing a productive

one (Sfard, 2007). When a student holds a rigid-and-faulty *narrative* about the way a problem should be solved, we can address it as a *Situational Misconception*. In order to facilitate a shift in the narrative, a teacher might need to follow the core ideas of conceptual change: In terms of Posner, Strike, Hewsonand Gertzog (1982), she needs to make the students acknowledge that the current path does not lead them anywhere and should be refuted (dissatisfaction). In addition she should make sure that the new concept is intelligible, plausible and efficient in the eyes of her students, if she would like them to adopt this new concept.

A math *problem* is defined by Schoenfeld (1985) as a question for which the solution path is not known to the solver (in contrast with an *exercise*). Many studies in this field investigate students' attempts to solve problems on their own, in small groups and with computers. Most of these studies adopt a constructivist approach, with an ultimate goal of a guiding students in order to become active agents for their own learning (Zimmerman, 2008). Thus, a teacher has an important role in scaffolding such learning; she needs to serve as a facilitator of the learning, rather than mere instructor (Abdu & Mavrikis, 2016). She needs to be highly prepared to support a solution for a problem that sometimes has an open end, and usually has various paths to the solution (Abdu & Schwarz, 2012; Abdu and Mavrikis, 2016). In a way, she needs also to "unlearn" some of the materials: Experienced math-problem-solvers usually will make automatic moves in their solution (Arcavi & Isoda, 2007). These moves are done unconsciously, since they are a part of the teachers' "tool kit". *Unlearning* is quite a challenge for teachers, and as a result many teachers fail to "connect" with the difficulties their students experience (Ben-David, 2007).

In this paper I claim that it is important to adopt the conceptual change theoretical framework for the teaching of math problem solving. I use *Situational Misconception* in order to describe and understand a sequence of events in which teacher gives ill support to a group of two students.

The context of the episode

Background

I analyze the behaviors of two 8th grade students who solve a math problem -"the city", together. The problem was designed for three double lessons. Students were instructed to use Geogebra – A software that affords the creation of dynamic geometrical and algebraic objects in a Cartesian domain (Stahl, 2009). It is a part of a full-year course in computer-supported collaborative math problem solving, led by an experienced teacher. The teacher was guided to adopt a constructivist stance – acting as a moderator of learning, rather than direct instruction.

The problem

I bring the *City* problem (Based on Prusak, Hershkowitz & Schwarz, 2012), as it was presented in the beginning of the first meeting, by the teacher.

"...the city council is going to build an energy center[...].This energy center needs to provide energy for the heating and cooling of seven public institutions of the city. All of the 7 public institutions pay good, equal, money [...] for the building of that energy center [...].We need to decide where to put the energy center in a way that will make as many as possible institutions, and people, happy. Note, when the length of the tubes between the energy-provider and the consumer increases, more energy is lost, and the energy efficiency gets smaller."

From a mathematical point of view, this problem asks if there a point that is equidistant to *any* given seven points?

Preparing to support the solution

This is not an easy problem for 8th graders. In congruence with Prusak, Hershkowitz and Schwarz, (2012), the teacher, along with the research team, broke the problem to three stages. *First stage*: there are only three institutions and the distances between them are equal – they form an equilateral triangle. In this case, the equidistant point is the *angles bisectors' /perpendiculars' /medians' intersection*. Note that in the case of an equilateral triangle it does not matter, since the three loci are at the same point. The students are familiar with these three concepts. *Second stage*: the distances between these three institutions are not equal, and they form a general triangle. The question in this stage is, what is the point that is equidistant to the three vertices of a general triangle? The former stage leads the solver to a conflict at this stage. Whereas in the former stage the solution is quite simple, it does not work for the case of a general triangle. Instead, the point that is equidistant to all vertices of a general triangle is the (1) *center of its circumscribed circle*, and, (2) *meeting point of the three*

perpendicular bisectors. Further elaboration about the math behind these solutions will be brought below. The students are unfamiliar with these concepts. *Third stage:* Solve the problem for the case of seven points. An equidistant point exists only when these 7 points are located on one circle. The equidistant point will be the (1) *center of that circumscribed circle* and (2) *the meeting point of all the seven perpendicular bisectors.* Again, the students are unfamiliar with these concepts.

In accordance with these stages, the teacher first instructs the class to investigate a simpler case of the problem (first stage) - an equidistant point to three points in an equilateral triangle. Later on they will try to solve it for a case of a general triangle and last – try to generalize their conclusions for a case of seven points.

The teacher also prepares a supporting narrative [N1] for the solution. In order to understand her support, let's talk math for a little bit. The Narrative that the teacher tries to promote could be explained in figure 1. (1) We take the midpoint of segment FG. From this point, I, we create a perpendicular. (2) We locate point J somewhere on that perpendicular. (3) Points F and G are equidistant to J, since triangles Δ FJI and Δ GJI overlap. (4) Segments FJ and GJ are equal.

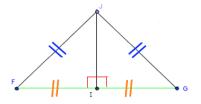


Figure 1. Teacher's hint - If we take the midpoint of segment FG and create a perpendicular, any point J on that perpendicular will be equidistant to F and G. Thus, FJ equals JG.

From here on we have two possible solutions. The first solution: Every given point, H (See figure 2), which maintains HJ=FJ=GJ, will help forming a triangle Δ FGH. The vertices of this triangle are all equidistant to point J. The conclusion in this case is: *The point (J) that is equidistant to all vertices of a general triangle is the center of its circumscribed circle*. In order to find such a point with the help of Geogebra, the students need to form a circle with Radius that is equidistant to point J. The center of this circle will be located at point J. All the points that are on this circle are equidistant to point J, since it is the center of the circle; segments HJ, FJ and GJ are the radiuses of this circle. Therefore, any point H on this circle will be sufficient to create a triangle Δ FGH, with point J as the point that is equidistant from all of the vertices of this triangle.

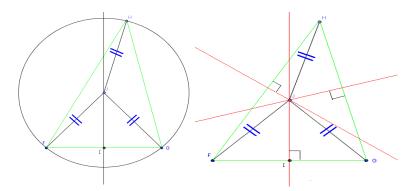


Figure 2. (Left) The point that is equidistant to all vertices of a general triangle is the center of its circumscribed circle. (Right) The three perpendicular bisectors of any triangle meet in one point; this point is equidistant from all the vertices of that triangle.

Another solution will be the three perpendicular bisectors of any triangle meet in one point; this point is equidistant from all the vertices of that triangle (same point as the center of a triangle's circumscribed circle). In order to find this point, let us remember that if we take the midpoint of segment FG and create a perpendicular, any point J on that perpendicular will be equidistant to F and G. Thus, FJ = JG (Figure 1). If we take section HG (figure 2, on the right), we can create perpendicular bisector that meets line GJ at point J. Since HJ=GJ and GJ=FJ, then FJ=HJ. Thus, point J is equidistant to all three vertices F, G and H.

Early stages of the solution

The team under scope has two students: Halel and Amir. They work together on two computers, while constantly monitoring each other's work. They pretty quickly come up with a shared understanding, like the rest of the class, that the equidistant point in the case of equilateral triangle is the angle-bisectors' intersection. They come to this understanding based on models they build with Geogebra. When Halel and Amir try to find a solution for a general triangle, they split. Each of them works next to his own computer, but they communicate orally at all times. Both come to the conclusion that the solution for the first stage is not valid in this case. They manage to find a solution for simpler case: The equidistant point from all vertices, in the case of *right-angled* triangle is the midpoint of the hypotenuse (see figure 3). On that note ends the *first lesson*.

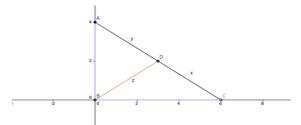


Figure 3. The point (D) is the midpoint of the hypotenuse, and thus is equidistant to all vertices of a right angled triangle.

The class goes back, for the *second lesson*. The teacher reminds the class what would be their upcoming steps - they need to find a point that is equidistant from the three vertices of any triangle. In addition, she gives a little hint that regards N1 - "Your job now is to go to a general triangle, ok? ... Another thing that you can do, anyone that encounters difficulties, is to start with two points, not three, and then move on to three points",

Halel and Amir continue to solve the problem. They build a faulty narrative [N2]: In the case of a general triangle, the equidistant point is on its longest edge. They investigate this point and see that this hypothesis was wrong, and as a result they try make sense of their conclusions for the case of a right-angled triangle, trying to find out why it works for the right angled triangle but not for the case of a scalene. Amir raises another Narrative, [N3] Solve the problem with the use of Pythagoras's theorem. This direction is irrelevant since the theorem is valid only for the case of a right angled triangles.

The episode: Teacher's intervention

The teacher joins Amir and Halel at this point, and after a quick attempt from the students' side to explain their hypotheses, the teacher recognizes that the directions they chose [N2 and N3] were non-productive. Since she wants the students to solve the problem together, she does not give them the solution and decides to assist them with the pre-planned support [N1], without *refutation* of their two narratives. She ignores their narratives and helps them to understand that there is more than one point that is equidistant from *two* points.

Teacher: [Looks at the Geogebra model in Amir's computer]: " Is it possible to try... It is possible to try to get you out of this mess? ... Choose two points, anyone you'd like. Say, AB or whatever, does not matter just two points. Now, look for a point that is equidistant from A and B. "

[Amir creates a median to AB, as could be seen in figure 4]

- Teacher: "Now, try to find another point that is equidistant from the two points."
- Halel: "Is it supposed to be on the median?"
- Teacher: "What?"
- Halel: "This point [D] is already equidistant...So everything that will be related to that will be equal! [Screams] Ahh, I got it!!! Move away! [To Amir]"

Amir: [Looks at Halel] " *This is what I am trying to say to you for half an hour now!!! But you would not listen*".

[Amir and Halel turn, each one to his own computer]

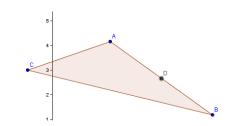


Figure 4. In triangle ABC, point D is equidistant from A and B.

At this point, three narratives are at stake. The first is the conjecture that the desired point is on the longest segment [N2], the second is that "it has to do with Pythagoras's theorem" [N3] and then there is the teacher's new narrative [N1].

Solution attempt 1

Amir: "We know that the triangle is right angled, and we know that [...] this, square [Points at section AC] plus this, square [Points with his fingers to section CB] equals to this, square [Points at section AB]. So we can define them [AC and CB] as half [of AB]. Half of this [Points at section AB] equals to this half [Points with his fingers to section AC] OK?...So what I am saying is [that] when you take here the median [Points at section AB] ...then it [AB] equals to the two halves [AC and CB]"

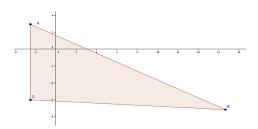


Figure 5. Amir's Geogebra model of a right angled triangle.

Amir explains now to Halel and the teacher why he thinks the solution for the right angled triangle is the middle of the hypotenuse. By doing so he will make two mistakes: First, he assumes that the formula $AC^2+BC^2=AB^2$ is equivalent to the formula AC+BC=AB (See Ben-David, 2007, about this particular misconception). Second, he assumes that if AC+BC=AB (which is completely wrong), then AC=AB/2. He starts with a hasty sketch of a right angled triangle. Amir uses these wrong assumptions and moves forward, based on these assumptions he assumes that these narratives will be applicable for the case of any triangle.

Amir: "Then I moved from here to here [Moves point 'A' so the triangle looks like one in the figure 5]... I now try to play with this point [Points with his fingers to segment AB] which is exactly what I wanted to do [Grabs the computer mouse, creates a midpoint D to section AB]. So the midpoint [of section AB] ...is a fixed point. Now I need to make another point [adds a point to the drawing] I put it on point D and can find [equidistant point]...[Creates a point G]

Amir still thinks that the "point that is equidistant from all three vertices of any triangle, is on segment AB, which is the longest segment. His plan is to use the computer simulation, create a point [G] on segment AB and move this point along this segment in order to find the equidistant point [N2]. He bases his claim on mathematical manipulations that are derived from [N3]. In order to meet with the teacher's instructions [N1: all

the points that are equidistant from A and B are on a perpendicular bisector], he integrates previous conclusion – in the case of a right-angle triangle, the point that is equidistant to all vertices bisects the hypotenuse.

Now, the teacher tells the students that she needs to leave, and without diagnosing how her hint was perceived, she takes off. After she does so, the two students keep hopping between solutions but do not appear like they are going to solve the problem.

Solution attempt 2

Amir builds a perpendicular bisector to AB, from its Midpoint, D. (see figure 6).

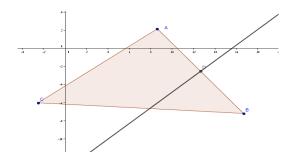


Figure 6. Amir's model - point D is in the middle of segment AB, and build a line that is perpendicular to this segment.

Amir tries to apply the teacher's narrative, for their case by building a perpendicular bisector. But he does not have the opportunity to develop narrative [N1] and Halel stops him with an attempt to build upon [N2] from another perspective.

Halel: "Amir, can I do something?"

Amir: "Just a second. [Puts a general point on the perpendicular, and erases it.] OK, you go on"

[Halel sits next to Amir's computer, as Amir looks at what he does. Halel erases the perpendicular from point D, and creates a midpoint E to section CA, and a midpoint F to section BC (Figure 7). He then tries to create three segments – EF, FD and DE and erases them at once.]

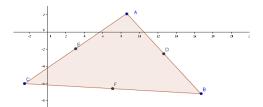


Figure 7. Points D,E,F are the medians of sections AB,AC and BC correspondingly.

The attempt to create a perpendicular bisector by Amir – which is closely related to [N1], is stopped by Halel. This might be a sign for Halel's inability to integrate this narrative into his mental model. Halel takes a step back and connects the three midpoint of the three segments. We cannot tell what Halel's ideas was, but it appears to be an integration of [N2] that claims that the point that is equidistant needs to be on one (longest) of sides of the triangle and [N1] that has to do with the creation of some sort of a segment that starts at the midpoints of the segments.

Let us note, in addition, that a productive path to the solution would have been a merge of the narratives of Amir and Halel: Creating three *perpendicular* bisectors from the three sides of the triangle will yield the point that is equidistant to all three vertices.

Discussion

The teacher's role in this study is of a facilitator that scaffolds the learning, rather than a direct instructor. As a result she gives the students hints, and not the solution. She comes with a pre-packed narrative, and disregards

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the narratives that were brought up by the students. Webb, (2009) explains that proper scaffolding of students' collaborative learning, requires an accurate and detailed analysis of the students' thinking before giving a prompt that is a best "fit" to those states. It is easy, but somewhat unfair, to critique a teacher's work, and I would hereby mention that the teacher involved is highly competent teacher. She wants her students to self-regulate their learning (Zimmerman, 2008). She also needs to cope with time limitation, in addition to the fact that she needs to move on and support other team's solutions. She has little time to diagnose the students' Situational-misconceptions, refute them, and to make sure that her hint was to lead the students anywhere. In addition, by all means I do not wish to claim that no learning was done. On the contrary, the technological scaffold, Geogebra, serves here as a tool that allows the students to refute their erroneous narratives (Hadas, Hershkoitz and Schwarz, 2006).

However, our obligation here is to use the conceptual-change framework in order to explain, where did she go wrong? In order to use the *conceptual-change* theoretical framework, in the context of online monitoring and regulation of collaborative learning, I define the term *Situational misconception* as a faulty narrative about the way the problem should be solved, which confines student's ability to solve the problem. Amir and Halel exemplify two main narratives [N2 & N3] that are situational-misconceptions. These situational-misconceptions are manifested as Geogebra models of possible solutions to the problem. The teacher instructs them to create a Geogebra model that serve as a manifestation of a third narrative. This is a technological scaffold (Pea, 2004) that was created by the teacher in order to foster the solution. As a result of their interaction with their teacher, they were introduced to an additional narrative [N1] that led to a couple of solution attempts that *failed*, since this narrative [N1] was incommensurable with their previous narratives [N2 & N3].

Failure of solution attempt 1

This solution attempt starts with [N3], which relies on the faulty assumption that there is a relation between the fact that the equidistant point is in the midpoint of the hypotenuse and Pythagoras's theorem. The *midpoint* appears in the teacher's hint [N1] as well, but has a completely different role: It defines the point from which a perpendicular is built in order to find all the points that are equidistant to the two vertices of the triangle's segment. Consequently, this does not change the students' assumption that the equidistant point in the case of scalene triangle is somewhere on the long edge [N2]. This leads also to the failure in solution attempt 2.

Failure of solution attempt 2

The equidistant point in the case of a right angled triangle appears on one of the sections (the hypotenuse). Thus, the equidistant point in the general case might be on one of the sections (wrong!) [N2]. Since the teacher's hint involved a point that is on one of the vertices – a midpoint [N1] – then if we build midpoints for the three segments of the triangle, and connect them, we might find a point that is equidistant from the three vertices.

Sfard (2007) uses Kuhn's term "incommensurability" in order to describe the use of the same term in two different conceptual frameworks. Sfard suggests that the interlocutors (students and teacher) should explicate how does the term they are using fits in their narrative, in order to proceed further. In our case, this is not a term, but a mathematical concept that was applicable in both narratives. In our case, this concept was the *midpoint*.

Posner, Strike, Hewsonand Gertzog (1982), claim that the teacher should make the students acknowledge that the current narrative does not lead them anywhere, before she adds a competing *plausible* narrative. Eventually, the added narrative [N1] confuses them, as they try to assimilate it to their narratives, instead of applying deeper change (accommodation). Nonproductive narratives were not refuted, which yielded the creation of two solution attempts, based on the use of the same concept – in different contexts. Accordingly, these two solution attempts are hybrids of all three old narratives [N1, N2 & N3].

Conclusions

From a theoretical perspective, the current work makes an attempt to analyze teacher's intervention in math problem solving, from the lens of the *conceptual change* framework. I use the term *Situational-misconception* to describe a nonproductive narrative; and see how the addition of a narrative to that situational-misconception, without refutation, leads to farther situational misconceptions. The adoption of such a framework serves fine-grained apprehension of how a misconception develops. It allows us to understand *why* the literature on *Conceptual change* adheres refutation of non-productive narratives, before adding new ones.

Moreover, we learn that the lack of refutation does not necessarily lead to continuity of the "old" misconception. While the literature on conceptual change mainly attempts to describe successful cases in which faulty concepts are replaced by new ones, the novelty of the *situational misconception* framework regards to the

identification of a twilight-zone: two competing narratives do not really impede each other, and ideas from both new and old narratives merge into new misconceptions.

This study contributes to in-class practice, by re-encouraging teachers to listen to their students' narratives carefully and refute them in a plausible way, when needed, before they add any competing narrative. In addition, teachers might find it beneficial to be highly familiar with possible misconceptions on the path to the solution of a problem in math. To rest our minds, it is important to mention that later on the teacher intervened in Halel and Amir's solution again. This time she was much more explicit; and still did not refute her student's nonproductive narratives. This led them to solve the problem.

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Dialogism: A Framework for CSCL and a Signature of Collaboration

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Abstract: As Computer Supported Collaborative Learning (CSCL) gains a broader usage in multiple educational scenarios facilitated by the use of technology, the need for automated tools capable of detecting and stimulating collaboration increases. We propose a computational model using *ReaderBench* that assesses collaboration from a dialogical perspective. Accordingly, collaboration emerges from the inter-twining of different points of view or, more specifically, from the inter-animation of voices pertaining to different speakers. Collaboration is determined from the intertwining or overlap of voices emitted by different participants throughout the ongoing conversation. This study presents a validation of this model consisting of a comparison between the output of our system and human evaluations of 10 chat conversations, selected from a corpus of more than 100 chats, in which Computer Science students debated on the advantages and disadvantages of CSCL technologies (e.g., chat, blog, wiki, forum, or Google Wave). The human evaluations of the degree of collaboration between the participants and the automated scores showed good overlap as measured by precision, recall, and *F1* scores. Our overarching conclusion is that dialogism derived from the overlapping of voices can be perceived as a signature for collaboration.

Keywords: CSCL, dialogism, collaboration assessment, cohesion, voice inter-animation

Introduction

Computer Supported Collaborative Learning (CSCL) technologies, with emphasis on chats and forums, have gained a broader usage as a viable alternative to classic educational scenarios. Such technologies facilitate the development of learning environments in which knowledge is collaboratively built and shared (Stahl, 2006), based on the inter-twining of collective and individual learning processes (Cress, 2013).

Dialogism was introduced by Bakhtin (1981) as having multivocality and polyphony as key features. Koschmann (1999) later proposed dialogism as a paradigm for CSCL. Accordingly, multivocality is centered on the multitude of meanings and the dialogue between multiple voices, whereas polyphony encapsulates multiple points of view and voices while focusing on their inter-animation, as well as the inter-relationships captured in their co-occurrences and overlap. Wegerif (2006) also considered dialogism as a theoretical starting point that can be used for developing tools to teach thinking skills. As Bakhtin (1981) proposed, voices contained within utterances influence each other, interact one with another and can be reflected one within the other. This process of voice inter-animation occurs progressively from simple repetitions to complex referential relationships between utterances. In addition, the inter-animation of voices or of personal points of view is a key component for ensuring the success of a collaborative learning activity (Wegerif, 2006). However, only a few elaborations of CSCL models based on dialogism have been proposed, and even fewer approaches provide automatic analytic tools – e.g., Dong's design of team communication (Dong, 2005), *Polyphony* (Trausan-Matu, Rebedea, Dragan, & Alexandru, 2007), or the *Knowledge Space Visualizer* (Teplovs, 2008).

Following from our development of several systems inspired from the dialogical approach (i.e., *PolyCAFe* (Trausan-Matu & Rebedea, 2010; Dascalu, Rebedea, Trausan-Matu, & Armitt, 2011; Trausan-Matu, Dascalu, & Rebedea, 2014) and *ReaderBench* (Dascalu, Trausan-Matu, & Dessus, 2013a), we propose a computational model to assess collaboration based on the inter-twining or overlap of voices pertaining to different speakers, therefore enabling a transversal analysis of subsequent discussion slices. We present a large-scale validation consisting of a comparison between the output of our system and human evaluations. In addition, we describe the results of a study with multi-participant chat conversations in which members were asked to debate on given topics and were assessed in terms of the collaboration among themselves. Our overarching conclusion is that dialogism derived from the overlapping of voices can be perceived as a signature for collaboration.

Philosophical implications of dialogism and the polyphonic model

Dialogism was introduced by Bakhtin (1981, 1984) and is centered on dialogue reflected in "any kind of human sense-making, semiotic practice, action, interaction, thinking or communication" (Linell, 2009, pp. 5-6). This definition of dialogism is naturally focused on the dialogue between two or more individuals exchanging utterances, but may well be present in any text as "life by its very nature is dialogic ... when dialogue ends, everything ends" (Bakhtin, 1984, p. 294). In addition, dialogue can be also perceived from a more abstract perspective as having multiple valences: 'internal dialogue within the self' or 'internal dialogue' (Linell, 2009, ch. 6), 'dialogical exploration of the environment' (Linell, 2009, ch. 7), 'dialogue with artifacts' (Linell, 2009, ch. 16), 'dialogue between ideas' (Marková, Linell, Grossen, & Salazar Orvig, 2007, ch. 6) or 'paradigms' (Linell, 2005, ch. 6). Nevertheless, in each context, discourse is modeled from a dialogical perspective as interaction with others, essentially towards building meaning and understanding.

In order to properly introduce the polyphonic model presented in detail later on within this section, we must first present the three core and inter-dependent concepts of discourse analysis: *utterances* briefly defined as units of analysis, *voices* as distinctive points of view emerging from the ongoing discussion, and *echoes* as the replication of a certain voice, the overtones and repetitions of the specific point of view that occur later on, with further implications in the discourse. Although the complexity of an utterance may vary greatly from a simple word or exchange to a set of inter-twined utterances or even to an entire novel (Bakhtin, 1986), our analysis adheres to Dong's perspective of separating utterances based on turn-taking events between speakers (Dong, 2009). Therefore, introducing a new point of view or contribution from a different participant divides the discourse by potentially modifying the inner, ongoing perspective of the current speaker. At a more fine-grained level, words, seen as the constituents of utterances, provide the liaisons between utterances and deepen the perspective of others' contributions into one's discourse. Obviously, utterances may contain more than a single voice, as well as alien voices to which the current voice refers (Trausan-Matu & Stahl, 2007). An *alien* voice is part of a turn uttered by a given participant that is later replicated in another one, marking therefore the transfer among different participants and their corresponding points of view with regards to the voice's central word.

Therefore, the main goal of a discussion can be described in terms of voice inter-animation and achieving true *polyphony* (Bakhtin, 1984) in which conflicting views, various angles, and multiple perspectives concur; all the previous aspects should also be covered in a truly collaborative conversation. However, as voices express ideas and opinions, polyphony can be used to perform a deep dialogical discourse analysis by summing up multiple voices co-occurring within the same discussion thread.

Nevertheless, we must also emphasize an intrinsic problem that "it is indeed impossible to be 'completely dialogical', if one wants to be systematic and contribute to a cumulative scientific endeavor" (Linell, 2009, p. 383). The later point of view also augments the duality between individual involvement and actual collaboration throughout a given CSCL conversation, as it is impossible to focus on both the animation with other participants' utterances and sustainably provide meaningful contributions. In the end, a balance needs to be achieved between individuals, without facing discourse domination in terms of participation.

The *polyphonic model* (Trausan-Matu, Stahl, & Zemel, 2005; Trausan-Matu & Stahl, 2007; Trausan-Matu et al., 2014) follows the ideas of Koschmann (1999) and Wegerif (2005) and investigates how Bakhtin's theory of polyphony and inter-animation (Bakhtin, 1981, 1984) can be used for analyzing the discourse in chat conversations with multiple participants for which classic approaches are not appropriate. Therefore, the polyphonic model focuses on the idea of identifying voices in the analysis of discourse and building an internal graph-based representation, whether relying on the utterance graph (Trausan-Matu et al., 2007) or the cohesion graph (Dascalu et al., 2013a). To this end, links between utterances are analyzed using repetitions, lexical and semantic chains, as well as cohesive links, and a graph is built in order to highlight discussion threads. Nevertheless, in both internal representations, lexical or semantic cohesion between any two utterances can be considered the central liaison between the analysis elements within the graph.

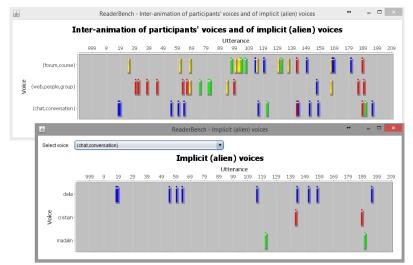
Moreover, of particular interest is the multi-dimensionality of the polyphonic model (Trausan-Matu, 2013). First, the *longitudinal* dimension is reflected in the explicit or implicit references between utterances, following the conversation timeline. This grants an overall image of the degree of inter-animation of voices spanning the discourse. This polyphony can now be used as a signature for collaboration, as the interactions between multiple participants of the conversation are reflected in their voices. Second, *threading* highlights voices evolution in terms of the interaction with other discussion threads. Third, the *transversal* dimension is useful for observing a differential positioning of participants, when a shift of their point of interest occurs towards discussing other topics.

Dialogical voice inter-animation model

From a computational perspective, until recently, the goals of discourse analysis in existing approaches oriented towards conversations analysis were to detect topics and links (Adams & Martell, 2008), dialog acts (Kontostathis et al., 2009), lexical chains (Dong, 2006), or other complex relations (Rosé et al., 2008). The polyphonic model emphasizes the Natural Language Processing dimension of the analysis by taking full advantage of Latent Semantic Analysis (Landauer & Dumais, 1997), Latent Dirichlet Allocation (Blei, Ng, & Jordan, 2003), semantic distances from the lexicalized ontology *WordNet* (Budanitsky & Hirst, 2006), and Social Network Analysis (Wasserman & Faust, 1994).

The voice identification process resides in building lexical chains and merging them into semantic chains through cohesion (Dascalu, Trausan-Matu, & Dessus, 2013b). Due to the limitation of discovering lexical chains (Galley & McKeown, 2003) through semantic distances in ontologies (Budanitsky & Hirst, 2006) that only consider words having the same part-of-speech, the *merge* step is essential as it enables consideration of different parts-of-speech and unites groups of concepts based on identical lemmas or high cohesion values. Therefore, an iterative algorithm similar to an agglomerative hierarchical clustering algorithm (Hastie, Tibshirani, & Friedman, 2009) is used. In order to merge clusters, the algorithm starts from the identified lexical chains seen as groups of already clustered words and uses the cohesion between the corresponding groups of words as the distance function if this value is greater than an imposed threshold.

As semantic chains span across the discourse, the context generated by the co-occurrence or repetitions of tightly cohesive concepts is similar to the longitudinal dimension of voices. Echoes can be highlighted through cohesion based on semantic similarity, while the attenuation effect is reflected in the considered distance between analysis elements. Moreover, by inter-twining different semantic chains within the same utterance, we are able to better grasp the transversal dimension of voice inter-animation. Therefore, after manually selecting the voices of interest, the user can visualize the conversation as an overlap of co-occurring semantic chains that induce polyphony (see Figure 1). The chart follows the conversation timeline expressed in utterance identifiers and a voice is displayed within the interface as the three most dominant concepts (word lemmas). Different speakers that uttered a particular voice are demarcated with randomly assigned colors, consistent throughout a conversation for each participant.



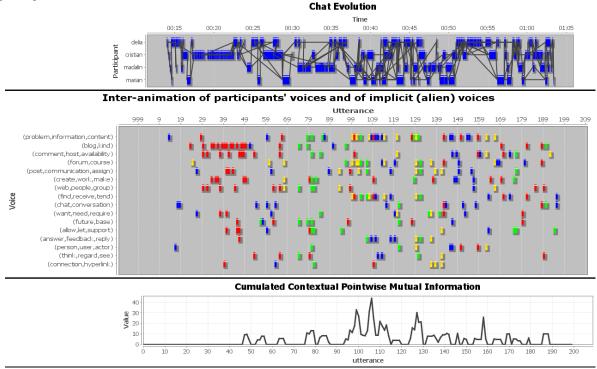
<u>Figure 1.</u> Voices (e.g., chat - conversation) split per participant and their corresponding distributions throughout the conversation.

In order to achieve genuine collaboration, the conversation must contain threads of utterances integrating key concepts or 'voices', that inter-animate in a similar way to counterpoints in polyphonic musical fugues (Trausan-Matu et al., 2005; Trausan-Matu & Stahl, 2007). As collaboration is centered on multiple participants, a split of each voice into multiple viewpoints pertaining to different participants is required. A *viewpoint* consists of a link between the concepts pertaining to a voice and a participant, through their explicit use within one's contributions in the ongoing conversation. We opted to present this split in terms of implicit (alien) voices (Trausan-Matu & Stahl, 2007) (see Figure 1), as the accumulation of voices through transitivity in inter-linked cohesive utterances clearly highlights the presence of alien voices. In addition, this split

presentation of semantic chains per participant is useful for observing each speaker's coverage and distribution of dominant concepts throughout the conversation.

After identifying the semantic chains that become voices and, in accordance to Miller's law (1956), a simple moving average (Upton & Cook, 2008) was applied on the voice distribution for five datum points representing consecutive utterances, with a split horizon of one minute between adjacent contributions. In other words, we weighted the importance of each concept occurrence over five adjacent utterances if there were no breaks in the discourse larger than an imposed, experimentally determined, threshold of one minute. Exceeding this value would clearly mark a stopping point in the overall chat conversation, making the expansion of the singular occurrence of the voice over this break unnecessary. This step of smoothing the initial discrete voice distribution plays a central role in subsequent processing as the expanded context of a voice's occurrence is much more significant than the sole consideration of the concept uttered by a participant in a given contribution.

Moreover, by applying *pointwise mutual information* (PMI) (Fano, 1961) between the moving averages of all pairs of voice distributions that appear in a given context of five analysis elements, we obtained a local degree of voice inter-weaving or synergy (Dascalu et al., 2013b). Therefore, collaboration is assessed as the cumulated PMI value obtained from all possible pairs of voices pertaining to different participants (different viewpoints) within subsequent contexts of the analysis. From an individual point of view, each participant's overall collaboration is computed as the cumulated mutual information between an individual's personal viewpoints and all other participant viewpoints. In other words, by comparing individual voice distributions that span throughout the conversation, collaboration emerges from the overlap of voices pertaining to different participants.



<u>Figure 2.</u> Collaboration evolution viewed as voice overlap between different participants (intertwining of different viewpoints), including the automatic identification of intense collaboration zones in contrast to the conversation timeline and utterance distribution.

Figure 2 presents the voices with the longest semantic chain span throughout the conversation and displays the tight correlation between the conversation's time evolution depicting the links from the cohesion graph (Dascalu et al., 2013a) among participants' utterances ordered chronologically and the results from our collaboration assessment model. A high density of links between participants determines collaboration, whereas timeframes with monologues from a single participant (e.g., utterances with IDs ranging from 27 to 50) have limited or no collaboration. Afterwards, collaboration increases as multiple participants become involved in the ongoing discussion. In addition, within the cumulated contextual PMI view, all of the voices from the conversation are considered (even those that have as low as 3 constituent words); this explains the greater

cumulative values encountered in the graph. Each peak of collaboration obtained through PMI corresponds to a zone with a high transversal density of voices emitted by different speakers (e.g., utterances with IDs ranging from 95 to 105 from the following excerpt that involves all participants involved in the conversation):

Cristian:	one thing about wiki. it is easy for many people to post on them
Marian:	you can also find good information on forums
Cristian:	but if no one is keeping tab on the content it can get pretty confusing
Marian:	and you can also search for information on forums
Marian:	and anyone can post on forums
Madalin:	in forums knowledge tends to be dispersed and somewhat lower in density
Marian:	I agree
Delia:	me too

Validations of collaboration and the identification of collaboration zones

The validation experiment focuses on the assessment of 10 chat conversations, selected from a corpus of more than 100 chats, that took place in an academic environment in which Computer Science students from the 4th year undergoing the Human-Computer Interaction course at our university debated on the advantages and disadvantages of CSCL technologies (e.g., chat, blog, wiki, forum, or Google Wave). Each conversation involved 4 or 5 participants who each first debated on the benefits and disadvantages of a given technology, and then later proposing an integrated alternative that encompassed the previously presented advantages. Afterwards, 110 4th year undergraduate and master students were asked to manually annotate 3 chat conversations, grading each participant on a 1-10 scale in terms of collaboration (inter-change of ideas with other participants) and identifying intense collaboration zones as segments of the conversations with a high degree of collaboration among the participants.

We opted to distribute the evaluation of each conversation due to the high amount of time it takes to manually assess a single discussion (on average, users reported 1.5 to 4 hours for a deep understanding) (Trausan-Matu, 2010). In the end, we had on average 33 annotations per conversation and the overall results presented in Table 1 indicate a reliable automatic evaluation of collaboration. The high values of intra-class correlations (ICC) and Cronbach's alpha (see Table 1) between the evaluators of each chat indicate few disagreements between raters. Pearson correlations and non-parametric correlations (Spearman's Rho) were determined between automatic and human mean ratings for each conversation. The preliminary results of the experiments presented in detail in this paper were included in Dascalu, Trausan-Matu, and Dessus (2014).

Conversation	Average ICC among raters	Cronbach's alpha among raters	Pearson correlation	Agreement (Spearman's Rho)
Chat 1	.944	.969	.846	.900*
Chat 2	.769	.821	.157	.100
Chat 3	.641	.727	.759	.300
Chat 4	.871	.907	.932	.900*
Chat 5	.936	.960	.892	.700
Chat 6	.949	.958	.897	.462
Chat 7	.853	.907	.537	.600
Chat 8	.890	.923	.326	.400
Chat 9	.886	.969	.540	.400
Chat 10	.703	.862	.636	.600
Average	.844	.900	.652	.536

Table 1. Collaboration assessment (*p < .()5)

As an interpretation of the results presented in Table 1, we can observe that predictions are accurate except for two conversations in which we could identify atypical behaviors: specifically for chat 8 – dominance of the conversation by certain participants at given moments – and specifically for chat 2 – similar involvement of multiple participants made the differentiation among them more difficult and more prone to error. Nevertheless, the overall evaluations are partially biased as some raters took into consideration quantitative

factors to estimate collaboration (i.e., the number of contributions) instead of focusing on the quality of the dialogue and on the way utterances, pertaining to different participants, inter-animated.

Conversation	No. of utterances	Manually annotated collaboration zones	Automatically identified intense collaboration zones	Р	R	F1	r
Chat 1	339	[37; 128], [167; 298]	[27; 38], [47; 66], [81; 128], [172; 238], [250; 279], [305; 321], [339; 343]	.84	.75	.79	.32
Chat 2	283	[13; 49], [68; 131], [144; 169], [193; 207], [229; 236], [245; 266]	[9; 46], [55; 75], [85; 113], [134; 149], [167; 184], [196; 203], [217; 233], [261; 271]	.63	.58	.60	.35
Chat 3	405	[36; 315]	[16; 20], [32; 136], [148; 189], [203; 226], [239; 255], [270; 301], [333; 377]	.80	.77	.79	.46
Chat 4	251	[19; 148], [184; 194], [203; 212]	[26; 60], [68; 125], [135; 139], [178; 244]	.72	.79	.75	.43
Chat 5	416	[28; 98], [120; 265], [280; 287], [346; 362]	[19; 228], [243; 280], [303; 314], [329; 361], [395; 403]	.73	.91	.81	.30
Chat 6	378	[64; 227], [248; 308], [321; 359]	[16; 27], [48; 90], [100; 229], [241; 370]	.81	.97	.88	.36
Chat 7	270	[40; 97], [108; 128], [145; 220], [232; 257]	[27; 39], [47; 93], [104; 110], [119; 135], [143; 170], [198; 202], [210; 221], [253; 261]	.78	.59	.67	.37
Chat 8	389	[30; 127], [140; 154], [189; 208], [235; 285], [299; 356]	[17; 39], [71; 161], [256; 283], [311; 382]	.73	.64	.68	.20
Chat 9	190	[51; 65], [80; 190]	[76; 85], [94; 114], [124; 173]	.95	.61	.74	.48
Chat 10	297	[27; 75], [89; 104], [139; 287]	[18; 57], [65; 124], [138; 150], [168; 179], [188; 196], [205; 209], [249; 258], [266; 287]	.75	.59	.66	.21
Average	•			.77	.72	.74	.35

Table 2. Identified intense collaboration zones

With regards to the identification of intense collaboration zones, each evaluator provided individual scores for collaboration and identified areas of collaboration in the conversation as intervals of type [x; y], where x and y are utterance IDs. All manual annotations were afterwards cumulated in a histogram that presented, for each utterance, the number of raters who considered it to be part of an intense collaboration zone. In the end, a greedy algorithm (Dascalu et al., 2013a) was applied on this histogram in order to obtain an aggregated version that reflected the intense collaboration zones emerging as an overlap of all annotations (see third column of Table 2). Based on the highlighted intense collaboration zones from Table 2, there is a good overlap reflected in the number of utterances marked as pertaining to a collaboration zone in both manual and automatic processes, as well as in terms of accuracy measured as precision, recall, and FI score between the annotated collaboration zones and our dialogical model. This indicates that our polyphonic-dialogic model is a good estimator of the annotated zones, therefore demonstrating the feasibility of our approach.

Conclusions and future research directions

Based on dialogism and on the polyphonic model, we have devised an automatic method capable of identifying collaboration based on the inter-animation of voices. As the validations demonstrated the accuracy of the models built on dialogism, we can state that the proposed methods emphasize the dialogical perspective of collaboration in CSCL environments. We opted to present the evolution of voice synergy through PMI instead of polyphony because our computational model uses co-occurrences and the overlap of voices within a given

context. In order to emphasize the effect of inter-animation that would induce true polyphony, we envisage the use of argumentation acts and patterns (Stent & Allen, 2000) for highlighting the interdependencies between voices and how a particular voice can shed light on another.

This approach opens up the exploration of multiple research questions. For example, one line of our research will further examine the relations between student collaboration in chat forums and performance in online courses. We also envision the use of this approach to assess narrative features of novels, highlighting different points of view from different characters. Still further, another set of experiments might focus on the assessment of students' self-explanations that can be perceived as a 'dialogue' between the author's text and students' thoughts viewed as echoes of the voices from the initial text, highlighting in the end relevant reading strategies employed by the learner (e.g., paraphrases, bridging, or knowledge inference). In sum, our approach opens up a host of opportunities to further explore collaboration from a dialogical perspective across a wide range of contexts.

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Boundary Interactions: Resolving Interdisciplinary Collaboration Challenges Using Digitized Embodied Performances

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Abstract: Little is known about the collaborative learning processes of interdisciplinary teams designing technology-enabled immersive learning systems. In this conceptual paper, we reflect on the role of digitally captured embodied performances as boundary objects within our heterogeneous two-team collective of learning scientists and computer scientists as we design an embodied, animated virtual tutor embedded in a physically immersive mathematics learning system. Beyond just a communicative resource, we demonstrate how these digitized, embodied performances constitute a powerful mode for both inter- and intra-team learning and innovation. Our work illustrates the utility of mobilizing the material conditions of learning.

Keywords: Interdisciplinary collaboration, embodied interaction design, mathematics education

Introduction

In the past decade, technology-enabled embodied interaction learning environments (TEELEs) have shown great promise for supporting collaborative learning in a variety of domains, and their design is a growing enterprise (Lindgren & Johnson-Glenberg, 2013). Designing systems that enable physically immersive and responsive pedagogical activities requires interdisciplinary collaboration between computer-science teams and learning-sciences teams. However, little is known about how these collaborating teams learn and design together.

Previous organizational studies (e.g., Engeström, 2001) and social studies of science (e.g., Hall, Stevens, & Torralba, 2002) have offered valuable insight into the nature of collaborative, interdisciplinary work "in the wild," however the computer supported collaborative processes of interdisciplinary teams designing learning systems for embodied interaction has not yet been an area of investigation. In general, many have lamented the lack of discussion and reflection on the learning processes of designers as design occurs, as opposed to much-elided (and perhaps much-edited) versions that accompany reports of finished products (Sengers, Boehner, David, & Kaye, 2005).

Here, we present our reflection-in-action (Schön, 1983) as a two-team collective of computer scientists and learning scientists building a virtual, animated pedagogical avatar (Johnson, Rickel, & Lester, 2000) with naturalistic, context-oriented, and user-responsive hand-gesture capabilities sourced from authentic human tutor behavior. Rather than focus on our learning outcomes, we explore how our design process (Koschmann & O'Malley, 2013) has been shaped by task objectives, coordination demands, and emergent material/digital design artifacts. Early on, our collaboration faced an impasse: how could the learning-sciences team (LS-team) communicate the embodied, multimodal instructional techniques that human tutors deploy for the computer science team (CS-team) to generate in a virtual tutor? Although human motion is notoriously difficult to codify, the computer-science team required a comprehensive representational scheme that would be conducive to their task of algorithmic proceduralization. To overcome this impasse, we devised a representation system using digitized, embodied physical performances. This system circumvents the bottleneck of codified inscription by capturing body motion directly.

We argue these material-turned-electronic embodied performances were key resources that occasioned both inter- and intra-team discovery and innovation. The performances acted as *boundary objects*—shared artifacts with interpretive flexibility that simultaneously supported the distinct purposes, meanings, and processes of two diverse stakeholders and could thus mediate their collaboration even in the absence of full consensus (Star, 2010). This paper details our emergent methodology in order to demonstrate how these digitized embodied performances enabled communication, analysis, and reflection on embodied interaction within and across our interdisciplinary teams.

Project background and objectives

Our collaborative project aims to integrate an animated, embodied pedagogical agent with a technology-enabled embodied-learning device for mathematics. The original device was designed to provide an interactive context for users to ground fundamental notions of proportionality in perceptuomotor activity. Learners discover strategies for achieving a non-symbolic goal state: they are required to make a computer screen green by using hand-held remotes to operate virtual cursors (Figure 1a). Unbeknownst to learners, the system generates green feedback only when their hand heights match a particular concealed ratio (e.g., 1:2) that the tutor manipulates (Howison, Trninic, Reinholz, & Abrahamson, 2011). In the original version, learners working in pairs or independently were guided through the discovery of techniques for keeping the screen green by a human tutor as they progressively enlist available mathematical artifacts (e.g., a Cartesian grid) to enact and symbolize their strategies (Figure 1a).

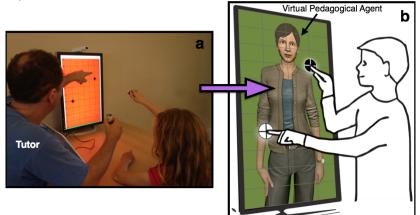


Figure 1. Multimodal tutorial tactics (a) will be emulated by a virtual pedagogical agent (character mesh by Hartholt et al., 2013) in the forthcoming design (b) of an embodied learning device for mathematics

Human tutors engage in complex forms of embodied interaction with children and the device to encourage exploration, highlight desirable patterns of activity, perform demonstrations, and foster learners' reflection on physical and symbolic aspects of their strategies (Flood, Schneider, & Abrahamson, 2014). These multimodal tutorial tactics enlist a rich array of bodily activity. Through gesture, tutors point out salient features in the virtual environment, rehearse past activity, and depict mathematical concepts. Tutors also use their body to model strategies for interacting with the device and often collaborate with the student to co-enact strategies. For example, in Figure 1a the tutor operates one remote while a student operates another to make predictions together.

Our project's goal is to design the virtual tutor so that it is capable of emulating the multimodal tutorial tactics the human tutor uses to support students' interaction with the device. The forthcoming design will feature an agent that faces the user through the screen and will have a touchscreen interface (Figure 1b). The LS-team's role in the design process has been to determine the relevant aspects of human–tutor embodied interaction the virtual tutor should enact, whereas the CS-team's role is to create a system that can generate these movements, adjusting them to the current interaction context and triggering them appropriately based on the child's progress. The joint design task provides each team a means to respectively contribute to different scientific communities (knowledge systems): For the CS-team, the project is a means to explore issues related to virtual agents and computer animation, whereas, for the LS-team, the project is a means to investigate and optimize embodied, multimodal instruction (both virtual and human) for mathematics learning. Thus, our two research teams can be seen as different stakeholders in a united design team facing an ill-structured design problem that neither group could solve alone (Star, 1989).

Design artifacts as boundary objects in interdisciplinary research teams

Fischer and colleagues (Fischer, 2000; Fischer & Ostwald, 2005) propose that heterogeneous design teams such as ours be seen as communities of interest, characterized by a *symmetry of ignorance* (Rittel, 1984), wherein neither team possesses the full breadth of knowledge to solve the problem independently, and thus both groups are equally important for the problem's resolution. Each side approaches the other's discipline with similar levels of naiveté. Fischer argues this symmetry of ignorance presents a powerful advantage in design: the process of negotiating different perspectives can disclose hidden aspects of design problems invisible to either group on their own, thus creating opportunities for learning (Fischer, 2000; Fischer & Ostwald, 2005).

A key to productive, creative interdisciplinary collaboration is in devising viable systems for communication (Mamykina, Candy, & Edmonds, 2002) that allow the two groups to negotiate and reach shared understandings (Resnick, 1991) despite their differences. Communication barriers, however, are inevitable when different communities of practice come together with their different knowledge bases and specialized languages (Fischer & Ostwald, 2005). Fischer argues that productive forms of negotiation arise via collaborative

interactions with co-developed *externalizations* (from Bruner 1996) that serve as boundary objects (Star & Griesemer, 1989). As boundary objects, these hybrid externalizations afford shared reference (Stahl, 2006), thus mobilizing process pragmatics, even as the teams maintain non-overlapping interpretations of the objects' significance (Akkerman & Bakker, 2011; Star & Griesemer, 1989; Star, 1989, 2010).

In particular, design artifacts (e.g., prototypes, plans) frequently serve as boundary objects (Bergman, Lyytinen, & Mark, 2007), providing a means to index unshared domain-specific terms and conceptualizations to publically shared elements of the perceptual field (Koschmann, LeBaron, Goodwin, & Feltovich, 2011). Sharing specific referents in joint perceptual fields—even while retaining distinct subjective senses and languages for these referents—allows participating researchers operating from within different knowledge systems to productively engage in practices that require cooperation. For example, this implicit "looseness" in co-reference to objects in the joint perceptual field has been implicated as crucial in enabling initial pedagogical discourse around conceptual content between instructors and learners (Newman, Griffin, & Cole, 1989).

Whereas past studies have discussed the role of static design artifacts such as physical models (e.g., Arias & Fischer, 2000) or diagrammatic plans (e.g., Henderson, 1991) as boundary objects, we extend this literature to the interesting case of dynamic, embodied performances.

Embodied interaction performances as boundary objects

The problem: Embodied interaction does not translate well

Our project has forced us to contend with the complexity of representing human physical activity. In particular, communicating about embodied interaction presents a formidable task. The LS-team needed to catalog a complex range of tutors' embodied activity and then convey this information to the CS-team for simulation. By analyzing a video corpus of human tutor interactions from a previous design research study, the LS-team identified 75 distinct variations of embodied interaction for the virtual tutor to perform. The CS-team needed to understand both the set of gestures required for the learning domain and the variation space for each gesture (i.e., all the different ways a certain gesture might be performed) as a prerequisite for designing the technology that would emulate these gestures artificially. Secondly, the CS-team needed to be able to accurately produce animation of this full movement range, which imposed both algorithm-design and data requirements.

One potential route was for the LS-team to supply the CS-team with a set of clips from the video corpus where human tutors interacted with students as they worked with the existing version of the system. However, this option proved impracticable given that key physical-layout features were going to change for the new configuration: The virtual tutor would now be the mirror image of the student, rather than sitting side by side as human tutors had done (see Figure 1a vs. Figure 1b). Thus, the raw video clips were inappropriate for direct emulation by the CS team because they were over-laden with incorrect contextual information and could not furnish optimal versions of the interactions for reproduction.

A serious problem was taking shape: how could we represent and catalogue precise choreographies of embodied interaction? Inscribing and archiving bodily motion has remained a challenge throughout history (Conquergood, 2014). In particular, describing human movement for accurate virtual or physical dynamical reproduction (e.g., sign-language conventions [Kilma & Bellugi, 1979] or dance choreographies [Kirsh, 2013]) is a non-trivial practice that has evolved over centuries (Guest, 1998). Existing notation schemes like Labanotation (Guest, 2005) and Laban Movement Analysis (von Laban, 1971) from dance or Stokoe notation (Stokoe, 1978) and HamNoSys (Hanke, 2004) for sign language require significant amounts of training to develop fluency in use. In addition, they are specialized for movements other than co-verbal gesture. Therefore, we needed to find an alternative method for representing and cataloguing choreographies of embodied interaction.

Devising a method to communicate: An emergent methodology

The method we devised for achieving the successful communication of embodied interaction specifications between our interdisciplinary teams altogether eschewed static verbal and diagrammatic description. We created a repository of physically re-enacted embodied interaction performances we wished to simulate and used this as a dynamic, embodied, living script for an actor to follow during a motion-capture session. In effect, we devised a way to let the bodily motion itself speak out our design intentions to each other.

Using tangible props, the LS-team fashioned a material analog of the virtual environment to investigate how to adjust particular forms of video-corpus-sourced instructional embodied interaction to accommodate the virtual tutor's new physical orientation of facing opposite the student. One member of the LS-team sat behind a transparent barrier and performed different tactics for another researcher playing a student. The LS-team was able to review each case of embodied interaction that they wished to reproduce by playing the corpus video and then directly recreating it in the material "virtual" environment (Figure 2a and 2b). This role playing and interacting with physical materials, a form of bodystorming (Schleicher, Privet, Jones, & Kachur, 2010) or experience prototyping (Buchenau & Suri, 2000), allowed for the emergence of authentic ways of redesigning particular tactics based on the natural constraints and affordances (Gibson, 1979) of the material and social space we built. Generating this information would likely be impossible through speculation, as the exact details of our interactions with the environment—such as in gesturing and object manipulations—typically escape our explicit conscious awareness (Schleicher et al., 2010).

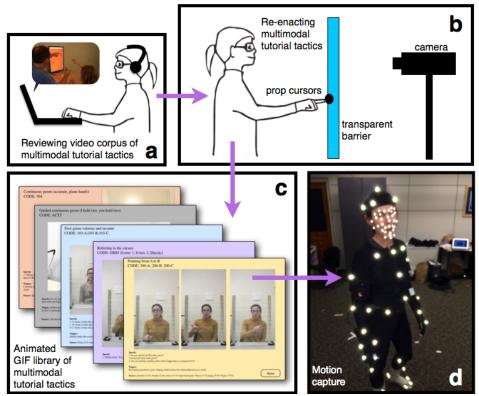


Figure 2. By directly watching human tutor interaction (a), the LS-team re-designed it for the new virtual environment with material props (b). These video-recorded re-enacted performances were converted into animated GIFs and organized into a library (c) which facilitated a motion capture session with the CS-Team (d).

The LS-team video-recorded each prop-supported embodied performance of the choreography of every multimodal tutorial tactic of interest. Next, the LS-team converted each clip of embodied interaction into animated Graphic Interchange Format (GIF) files, a format for short, looping "moving pictures" most recently popularized by the blogging platform Tumblr (Uhlin, 2014). The GIFs of multimodal tutorial tactics were organized by pedagogical function (e.g., gestural techniques for highlighting co-variation) to create a comprehensive library of digitized, animated embodied performances (Figure 2c). See http://goo.gl/8ImYYX for an example slide from the multimodal tutorial tactic library.

The animated GIF library of multimodal tutorial tactics was essential for helping the CS-team initially understand the problem space. In addition, this library also served as a living, moving script of embodied interaction to guide a member of the LS-team's physical performance of the tactics for a motion-capture session with the CS-team (Figure 2d). Because motion capture requires extensive calibration and set-up time, the entire set of embodied interaction had to be captured in a single session. Each GIF of embodied interaction from the library could be quickly watched, learned, and performed for capture. The library served as a direct choreographic resource and afforded accurate physical reproduction of 75 distinct motions in a single session.

For the CS-team, the motion capture performance was a product as well as a process of communication. The data generated is a direct input to their second task of building a system that synthesizes larger families of gestures. For the LS-team, the motion-capture performance became a way to communicate tacit professional expertise, which, we venture, is a form of felt know-how that is ultimately inarticulate (Dreyfus & Dreyfus, 1986; Polanyi, 1958; Ryle, 1984) and never fully translatable to words.

Learning from digitized embodied performances

The embodied performances recorded in the library and via the motion-capture session became durable, public, external representations for our interdisciplinary team to negotiate understandings of the phenomena at hand. Thus, the embodied performances played the role of external boundary objects facilitating communication and collaboration between teams. However, these collaborative and individual team interrogations of the performances also led to revelations that would likely have gone unnoticed otherwise, affording insight into issues in our respective domains as well as insight into design challenges we faced and needed to resolve together. Below, we provide specific between- and within-team examples of how we learned from the embodied performances as boundary objects.

Inter-team revelation: A collaborative design solution

Collaborative discussions about the embodied interaction performances led to a novel solution to a vexing design problem that may generalize beyond our project context. Real tutoring situations rely on the tutor's careful analysis of the student's online verbal responses. However, this is a particularly challenging task to accomplish computationally. How could the virtual tutor monitor what the child knows without eliciting and analyzing verbal responses? During reflections about the library and motion capture, we realized an alternative solution. Just as we had relied on embodied performances to communicate with each other during our project, we reasoned, the virtual tutor could potentially rely on embodied performances to communicate with the student. Namely, the agent can gauge the learner's perception of strategy by performing particular interaction techniques and then eliciting a simple yes/no evaluation from the learner as to whether the agent's embodied performance accurately reflects what the learner is attempting to do. Based on the response, the system can develop a model of the learner's perceived strategy. Instead of verbal processing, embodied re-enactment can thus be used as a tool for measuring the student's current understanding, taking advantage of the embodiment of the agent. The virtual tutor's performance would be recognizable to the learner as mimicry *because* the agent has a similar body (Núñez, Edwards, & Matos, 1999).

We suspect that this innovation in nonverbal assessment technique would be applicable for other tutoring systems with embodied virtual pedagogical agents across a broad range of domains that instruct and train particular forms of embodied interaction in complex environments (e.g., procedural training, Rickel & Johnson, 1999).

Intra-team revelations: Gaze and multi-phase gestures

During subsequent, independent analyses of the digitized embodied performances in the library, each team also revealed a new dimension of embodied interaction of interest to them.

The LS-team noticed that some of the embodied performances of multimodal tutorial tactics in the library had an unnatural quality to them, but at first they could not articulate why. After analysis and reflection on the library, they realized it was because the actor had stared into the camera for some of the performances and failed to re-enact naturalistic patterns of gaze to accompany the embodied interaction being performed (See http://goo.gl/8ImYYX "200-B" for an example of unnatural gaze). This led the LS-team to notice that their original analysis of the video corpus never explicitly attended to gaze. This is a significant omission as in natural face-to-face communication, speakers producing depictive gestures frequently look down at their own hands to direct their listeners' attention to the embodied aspect of their utterances and signal their relevance (Streeck, 2009). The team now plans to investigate the role that gaze plays in directing students to instructors' gestures as part of pedagogical tactics in order to better incorporate this phenomenon into the forthcoming design.

For the CS-team, the gesture documentation process led to discovery of the high prevalence of multiphase gestures not observed in the team's previous work on co-verbal gesture. Multi-phase gestures consist of several segments with variable form and repetition. They require more complex representational schemes and algorithms for manipulation, ultimately allowing animated characters to create more complicated and controllable gesture forms to convey very particular ideas.

Discussion

Overall, our case supports Fischer and colleagues' assertion that the *symmetry of ignorance* existing between heterogeneously composed design teams can be advantageous for design processes by forcing teams to devise innovative communication systems that later become springboards for collaborative, creative work and opportunities to learn. The communication system we devised served as a boundary object, generating individual intra-team revelations resulting in new discipline-specific knowledge as well as collaborative inter-team revelations resulting in new interdisciplinary shared knowledge (Figure 3).

Specifically, our case study demonstrates the value of using embodied performances to communicate in an interdisciplinary team of learning scientists and computer scientists. Our interdisciplinary design-process challenges were resolved by creating a new form of design artifact, a set of embodied performances that were archived systematically in an electronic library and then re-enacted by a human actor for motion capture. These material performances mobilized our collaboration by obviating the need to painstakingly work out and establish a shared verbal/symbolical language for describing embodied interaction with the learning device. Additionally, while discussing and interacting with the archived performances, we devised a design solution for dealing with assessment nonverbally that mirrored our own communicative process. At the same time, the evolving constraints imposed by each team on the other in the course of creating and analyzing the performances occasioned each team opportunities to reflect on their own practice and make unexpected discoveries (i.e., the prevalence of multi-phase gestures for the CS-team and the importance of gaze for the LS-team). In turn, these discoveries present both teams with future opportunities to pose important domain-specific research questions that were not possible to forecast at the project's inception.

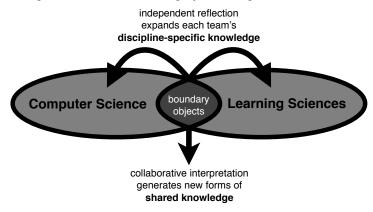


Figure 3. Interrogating embodied performances as boundary objects independently allowed each separate team to expand their discipline-specific knowledge. Collaborative interrogation of boundary objects led to the production of new, shared knowledge as a design solution emerged.

In retrospect, we believe it is not surprising that successfully conveying embodied interaction specifications ultimately required communication through bodily re-enactment. Particular mediums and modalities are simply more adept at carrying particular forms of information (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001). Further, the embodied practices of pedagogical interactions (e.g., how to effectively draw a student's attention to a mathematical pattern by pointing) represent a tacit form of professional know-how that may not be possible for its practitioners to translate into propositions (Dreyfus & Dreyfus, 1986; Polanyi, 1958). Independent of verbal exposition, embodied interaction performances anchor references in pragmatically loose yet mutually appreciable visual and physical-material forms, enabling dialog between collaborating teams. Embodied performances, as boundary objects, offered us a powerful tool for building a shared understanding of the problem space.

At the same time, however, an important benefit of boundary objects is that they allow for work without need for consensus (Star & Griesemer, 1989; Star, 2010). Indeed, our library of embodied performances offered a critical advantage beyond serving as a means for shared reference, in that each team could perceive the same performances differently. Because the library preserved actual rich, dynamic *performances* of embodied interaction, a sufficient level of detail existed for both teams to comprehend their particular phenomena of interest within the record. That is, the LS-team could look at a particular performance (i.e., a particular case of embodied interaction) and understand it holistically as a pedagogical tactic, whereas the CS-team could decompose the rich sequence of activity into composite parts, and begin re-organizing the performances by morphological similarity. Different granularities or units of analysis (Star & Griesemer, 1989; Star, 2010) are simultaneously possible with the preservation-modality being bodily motion itself.

As scientists approach new frontiers together—as is the case in our current project—they often rely on explorative bodily activity to make sense of new results for which they do not yet have verbal language to describe (Becvar, Hollan, & Hutchins, 2005; Ochs, Gonzales, & Jacoby, 1996). Architects and designers similarly use their bodies to imagine uncharted territory together before pinning concepts down in words or drawings (Murphy, 2004; Sema, 2014). However, in both science and design, the body's role as an epistemic resource in the process of invention and discovery—acting as a significant methodology in and of itself—is frequently simply left out of the record of procedure as legitimate and even pivotal to the practice.

We view the case we present here as testament to avoiding such omissions: embodied performances were an essential aspect of our collaboration and learning process. However, we only arrived at this solution serendipitously after many failed attempts to communicate.

Concluding Remarks

The nature of embodied learning technology poses new, difficult, and yet-to-be discussed challenges for collaboration between computer scientists and learning scientists. In particular, we conjecture that as TEELEs are scaled up, the need for virtual agents capable of embodied interaction—including naturalistic gestures, demonstrative action, and interaction with the user—will increase. Thus we hope our findings and leasons learned will be relevant to others working in interdisciplinary teams to design physically immersive learning technologies. In addition, we think that the recommendation to embrace digitized embodied performances as a means to communicate is likely useful to a broader audience of interdisciplinary teams designing for embodied and tangible interaction across a range of applications.

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Design Features for Computer-Supported Complex Systems Learning and Teaching in High School Science Classrooms

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Abstract: While research on teaching and learning about complex systems has achieved solid grounding in the learning sciences, few educational studies have focused on articulating design features for classroom implementation that can serve a modular purpose for building curricular and instructional experiences. Furthermore, despite the fact that several studies describe important roles for teachers in constructing successful classroom learning experiences, only a few of them examine how teachers' instructional practices, knowledge, and beliefs influence student learning outcomes and the extent to which teachers are interested and willing to teach through complex systems approaches. Furthermore, we do not know what supports teachers themselves say that they need to teach about complex systems in their classrooms. In this study, we present a curriculum and instruction framework that outlines how teaching and learning about complex systems in high school science classroom contexts can be done. We articulate the features of the framework and provide examples of how the framework is translated into practice. We follow with evidence from an exploratory study conducted with 10 teachers and over 300 students aimed at understanding change in teachers' instructional practices; the extent to which students learned from the activities; what teachers' perceptions were in terms of utility and usability; and what other supports teachers needed.

Keywords: Innovative Design Approach, Teaching, Science Education, Learning Outcomes

Introduction

The study of complex systems in natural and social sciences has become increasingly essential to understanding disciplinary and interdisciplinary content and practices (The National Academies, 2009). The study of complex systems is also featured prominently in the *Next Generation Science Standards* (NGSS) for K12 science in the U.S. Complex systems can be found in structures and behaviors in all aspects of our world. At the micro scale, an example of a complex system is a single fertilized egg developing to create differentiated cells that eventually become a human form. Macro-scale complex systems include businesses, cities, animal populations, and ecosystems. Although complex systems vary in their physical components, a common feature of all complex systems is the presence of multiple interconnected elements, parts, or individuals that communicate in nonlinear ways. The interactions among the parts form a collective network of relationships that exhibit emergent properties not observable at subsystem levels. When perturbations occur, the network may self-organize in unpredictable ways, allowing new properties to emerge.

While research on teaching and learning about complex systems has achieved solid grounding in the learning sciences (Hmelo-Silver & Kafai, 2011), few educational studies have focused on articulating design features for classroom implementation that can serve a modular purpose for building complex systems curricular and instructional experiences. Furthermore, despite the fact that several studies describe important roles for teachers in constructing successful classroom learning experiences (e.g., Perkins & Grotzer, 2005), only a few of them examine how teachers' instructional practices, knowledge, and beliefs influence student learning outcomes (Yoon et al., 2013; 2015; Randler & Bogner, 2009) and the extent to which teachers are interested and willing to teach through complex systems approaches. Furthermore, we do not know what supports teachers themselves say that they need to teach about complex systems in their classrooms. Addressing these gaps will be critical in the next few years in order to meet NGSS requirements.

In this paper, we respond to these needs by presenting a curriculum and instruction framework that outlines how teaching and learning about complex systems in high school science classroom contexts can be designed and implemented. We articulate the features of the framework and provide examples of how the framework is translated into practice for classroom implementation and for professional development (PD). We follow with evidence from an exploratory study aimed at understanding: 1) To what extent teachers thought the PD was usable; 2) To what extent teachers' instructional practices changed as a result of participating in the PD based on the framework; and 3) To what extent students learned from these curriculum and instruction activities. We also provide information in the discussion about what other supports teachers felt they needed.

Background: Complex systems in science education

Over the last 15 years, about 65 empirical studies have appeared in journal articles on the topic of complex systems in K12 education and of those, a large majority, have been geared toward science learning. Although an extensive review of the focus of these studies is beyond the scope of this paper, there are a number of themes that emerge in the research base such as understanding how students reason about complex systems (Assaraf et al., 2013; Levy & Wilensky, 2008; Grotzer, 2012), pedagogical approaches to supporting learning (Yoon, 2008, Hmelo-Silver et al., 2000), computational tools to build complex systems understanding (Yoon, 2011, Klopfer et al., 2009; Azevedo et al., 2005); and models for curriculum construction (Danish, 2014; Gobert & Clement, 1999). Despite this prevalence, no studies exist that investigate how pedagogical approaches, computational tools, and models for curriculum can work in the situated context of the science classroom where variables such as ability to address content standards are primary concerns for teachers. Likewise, very few studies have examined the role of the teacher in influencing student-learning outcomes. In a quasi-experimental study comparing two different instructional approaches to teaching complex ecological content, one study by Randler and Bogner (2009) showed that the teacher's teaching style had a strong impact on student academic learning. However, this study stands as a rare example of research investigating the teacher's role and incidentally was not the focal goal of the study. In other science education research, we do know that teacher attitudes, beliefs, knowledge, and skills can significantly influence the success of an intervention and even whether an intervention is adopted (Jones & Carter, 2007; Wallace & Kang, 2004). Clearly, more research is needed that includes designs to incorporate classroom and teacher variables to understand how new reform programs like the NGSS can work to improve science education in real classrooms.

To address this need, we constructed a complex systems curriculum and instruction (C&I) framework, in which teacher knowledge of context variables and content standard demands factored prominently in the design along side tools and practices known to improve student complex systems understanding. There are 4 major categories of the framework that are additionally aligned with the literature on needs and best practices for STEM teaching and learning. The first category is *Curricular Relevance*, which focuses on developing 21st century competencies (NRC, 2012), ensuring standards alignment (Desimone, 2009), and collaboration with teachers to promote teacher ownership (Ertmer et al., 2012, Mueller, 2008; Thompson et al., 2013). The second category, *Cognitively-Rich Pedagogies*, involves pedagogies that address situated needs in individual classrooms (Penuel et al., 2011), social construction of knowledge through collaboration and argumentation (Osborne, 2010), and constructionist learning by constructing models (Kafai, 2006). The third category, *Tools for Teaching and Learning*, builds knowledge with computational modeling tools (Epstein, 2008), teacher guides and student packets that provide scaffolds for learning (Quintana et al., 2004), and off-computer participatory simulations to support students' understanding of modeling and complex systems (Colella, et al., 2000). The fourth category, *Content Expertise*, builds deeper content understanding in complex systems (Yoon, 2008), biology (Lewis & Wood-Robinson, 2000), and computational thinking (NRC, 2010).

Based on the framework, our project engages teachers and students in learning experiences that build knowledge of scientific practices, complex systems, and biology using computational models. The project has built instructional sequences for five high school biology units – Genetics, Evolution, Ecology, the Human Body, and Animal Systems. Participants use an agent-based modeling platform called StarLogo Nova that combines graphical blocks-based programming with a 3-D game-like interface. The curricular materials take two or three days to complete. Examples of curricular and instructional activities built on this framework are found in Table 1.

Following the construction of the tools and curricula, we trained teachers in summer and school year PD workshops. We worked closely with teachers to understand implementation challenges and iteratively redesigned project resources to meet their classroom needs. In the next section, we discuss the context of the PD underpinned by the C&I framework, and provide evidence from an exploratory study that illustrates its impact in the classroom.

Table 1: BioGraph C&I framework categories and activities

BioGraph Categories	Activities/Strategies
Curricular relevance	Curricular emphasis on building 21st-century skills in problem solving, critical
	thinking, and self-directed learning.
	Close alignment with content, practices, and crosscutting themes in the NGSS (e.g.,
	systems).
	Collaboration with teachers as research partners through continual feedback about
	challenges in classroom implementation and collective problem solving to improve
	the project and to promote optimal implementation. Peer sharing facilitated through
	an online database where teachers post lesson plans and comments on implementation details.
Cognitively-rich	Consideration of and response to situated teaching contexts such as high ESL
pedagogies	populations (e.g., generation of more visual aids to improve cognitive engagement).
	Curriculum and instructional strategies anchored in social constructivist pedagogies
	(e.g., students working in teams co-constructing ideas through argumentation).
	Using StarLogo blocks-based graphical programming language with a low-level
	learning threshold, students learn to build simulations to construct understanding of
	scientific phenomena.
Tools for teaching and	Student interaction with models that are visual representations of scientific ideas.
learning	
	Visualization of dynamic processes of systems, such as self-organization and
	emergence, using StarLogo models. Visualization of system states at multiple scales.
	Student experiments using the models, collection and analysis of data, and drawing
	evidence-based conclusions.
	Easy-to-use teacher guides and student activity packs to promote teacher and student
	autonomy. Teacher guides for adapting and extending practice.
	Off-computer participatory simulations to engage teachers and students physically in
	systems that provide additional sensory and cognitive input for learning.
Content Expertise	Popular and academic literature about complex systems for teachers and students.
	Short movies, PowerPoint presentations, and detailed definition lists to develop
	systems understanding in the classroom. Student interactions with StarLogo models that explore biology content in detail.
	Some strategically selected content (e.g., evolution) to remediate known robust
	misconceptions.
	Models set up to allow students to explore the program that executes the model with
	the goal of developing skills related to computation, such as algorithmic thinking.
	Some models that require students to manipulate the program and construct their own
	systems.

Methodology

Context

In order to ensure that the utility of the project's resources could be optimally investigated, we also wanted to take care in constructing PD experiences that would support the efforts. To that end, we designed and conducted the PD following professional judgments about what constitutes state of the art characteristics of high quality PD: (a) aligned content; (b) active learning opportunities; (c) coherence with professional demands; (d) at least 20 hours in duration and spread over a semester; and (e) collective participation of teachers from the same school, grade, or subject (Desimone, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001). Of these five characteristics, we considered active learning to be particularly important. Due to the well-documented, steep learning curve teachers experience in adopting new technologies in their classroom (Aldunate & Nussbaum, 2013; Ertmer et al., 2012), we emphasized exposure to computers (Mueller et al., 2008) and extensive training on computers (Pierson, 2001). We also incorporated the other characteristics judged to be important for a quality intervention. For example, we achieved coherence with professional demands by providing close teacher-researcher collaboration. We delivered 40 hours of face-to-face PD. We also focused on collective participation by working only with high school biology teachers and, in some cases, working with several teachers from the

same school. Figure 3 provides the scope and sequence of professional development activities conducted in the summer 2012 workshop. In this exploratory study, we were interested in understanding what teachers learned and understood about the utility of the activities in terms of classroom practice and whether students' learning improved.

	Monday	Tue	esday	Wednesday	Thursday	Friday	
8:00 - 8:15	Room Open - Snacks and Coffee						
8:15 - 8:30		•					
8:30 - 8:45	Welcome and		me and	Welcome and	Welcome and	Welcome and	
8:45 - 9:00	Participatory Sim - Paper	Participatory Sim - Red		Participatory Sim - Angles	Participatory Sim - Kids as	Participatory Sim -	
9:00 - 9:15	Catchers	Why Construct? Why Argue?				Gamblers Dilemma	
9:15 - 9:30	Complexity Intro Video					Cumbioro Bilomina	
9:30 - 9:45	and Complex Systems			Why Model?	Plan Admin Day and		
9:45 - 10:00	Matrix with BioGraph				Scale Up	Calendaring Session	
10:00 - 10:15	Examples	Research	h Findings				
10:15 - 10:30	Differentiation Sessions (Teacher Presenter)	100000101	in mango				
10:30 - 10:45				BREAK			
10:45 - 11:00				Buffet of Complex Systems			
11:00 - 11:15				Resources/Pedagogy and	Working Groups -		
11:15 - 11:30	StarLogo Nova - Catching		ova - Ecology	Lesson Plan Construction	Differentiation and	Online Resource Forum	
11:30 - 11:45	Flies	Act	tivity	Argumentation and	Assessment	Offinite Resource Forum	
11:45 - 12:00				Collaboration Resources			
12:00 - 12:15							
12:15 - 12:30				Lunch - Radix Demo	Lunch - Stat		
12:30 - 12:45	Lunch	Lunch		Lunch - Maux Demo	Lunch - Oldi	Lunch	
12:45 - 1:00							
1:00 - 1:15	BioGraph Activity & Next	Argumentation and		BioGraph Activity and	BioGraph Activity and		
1:15 - 1:30	Generation Science	Collaboratio	on Resources	Next Generation Science	Next Generation Science	Sharing of Assessment	
1:30 - 1:45	Standards - Sugar	Student Acc	sessment and	Standards - Enzymes	Standards - Evolution	and Differentiation Work	
1:45 - 2:00			ollection				
2:00 - 2:15	Transport (Argumentation)	Data Ci	Ollection	(Argumentation)	(Argumentation)		
2:15 - 2:30		Parallel S	Session 1 -			Exit Surveys and Next	
2:30 - 2:45		Assessment (Working Group)/ Parallel Session 2		Model		Steps Check List	
2:45 - 3:00	Further Complexity			Building/Programming			
3:00 - 3:15			ntiation of	Extensions - Differentiated	Skills		
3:15 - 3:30				Session for Teachers	SKIIIS	Celebration!	
3:30 - 3:45		Lessons (wo	orking Group)				
3:45 - 4:00	Daily Wrap-Up						
	Color Coding Key						
			Blue	Pedagogy			
				Complex Systems			
			Orange	Argumentation			
			Purple	Computation			
			Red	Thinking/Modeling Break/Lunch			
		_	Teal	Research Wrap-Up/Celebration			
			White	wiap-op/celebration			

Figure 1. Scope and sequence of professional development activities in the summer workshop

Participants

We recruited 10 teachers from Boston area public schools– seven females and three males. The teachers came from a diverse set of schools. For example, the percent of students who were from minority race/ethnic groups ranged from 3 to 75; the percent who were eligible for free or reduced priced lunch ranged from 11 to 83; and the percent who scored at the proficient or advanced level on the state standardized science test ranged from 54 to 89. On average, the teachers had 7.7 years of teaching experience, with a range of 3 to 18 years. We collected student data from a total of 352 students (mainly comprised of freshman biology students).

Data collection and analysis

We conducted a mixed methods evaluation of the project implementation after the summer 2012 PD workshop and throughout the 2012 and 2013 school year. We collected surveys, interviews, and classroom observations of students and teachers to investigate the research questions. First, to investigate teachers' perceptions of the utility of project resources, we administered an 18-item Likert-scale and 8 short answer usability survey at the end of the summer workshop. Questions probed whether they believed the resources were useful to them, whether they would recommend the workshop to other colleagues, and whether they thought the PD was successful. Simple means are reported to illustrate teachers' perceptions of usability and interest in the project.

To understand how teachers' instructional practices changed, we used two data sources, preintervention and post-intervention surveys administered to students, which probed the extent to which they participated in learning through computers and simulations, and student learning using scientific practices that aligned with the project goals. The survey encompassed 44 items on a 5-point Likert-scale that ranged from no participation (1) to a lot of participation (5). A repeated-measures analysis of variance (ANOVA) was applied to the data to understand impact on instructional practices. We also administered year-end interviews with teachers to gather information about their perceptions of the project resources, how their knowledge and skills improved, to determine what aspects did or did not contribute to this improvement, and to understand how to redesign project resources to help teachers further improve. The interviews lasted for 45 minutes and were qualitatively mined by the research team to probe for indicators of project impact.

To determine the extent to which students learned while participating in the project, we administered two surveys to students. The first was a 14-point multiple-choice test that measured biology content related to the project. The second was two open-ended questions that provided scenarios about changes in biological complex systems. Students were asked to rationalize why the changes had occurred. Responses were scored on a scale of 1 (not complex) to 3 (completely complex) in four different categories of complex systems components (e.g., emergence of new properties at different scales). Repeated measures ANOVAs were also conducted on the data. In selected classrooms, student focus group interviews were also held to collect information about what they thought about learning biology through project activities and tools. Although more extensive mining of the interview response data is yet to be completed, we report on initial themes that emerged.

Results

Evidence that the PD was usable by teachers

Responses on all 18 Likert-scale items ranged between 4 (agree) and 5 (strongly agree). For example, teachers felt the workshop topics were relevant to the grades they taught (5); the information presented was useful to them (4.9); the information could be put into practice immediately (4.6); instructional guides were useful to their own learning (4.8); the exposure to agent-based modeling technology was useful to them (4.9); they would be able to use ideas about complex systems in their teaching (4.6); and they planned to share complex systems ideas with their colleagues (4.7). When asked whether they believed the PD was successful (and if so, why), teachers overwhelmingly responded positively referencing aspects of the PD they thought were particularly important in their learning:

"Ample instructional supplies and resources."

"Provision for teacher input and collaboration; great materials and instructional team."

"Practicing each activity and facilitation."

"I have used many simulations before but they don't drive home the major ideas. The

StarLogo lessons, I feel do. Our hands-on activities were extremely helpful."

"I learned a lot and will be able to confidently implement the program because we ran through and discussed them all, we talked a lot about...complex systems..."

Evidence of teachers' instructional practices and improved knowledge and skills

On the survey that investigated students' classroom experiences in the two main project factors, learning through computers and simulations ($\alpha = .872$), and student learning using scientific practices ($\alpha = .739$), student population responses indicated modest but significant gains in their classroom experiences. On the 5-point scale, responses showed an increase from 3.0 to 3.5 (p < .001) for learning through computers and simulations and 3.4 to 3.6 (p < .001) for learning using scientific practices. In teacher interviews, teachers felt that these instructional changes did not come at the expense of covering their standard science curricula, as evidenced in the following interview response from one teacher: "I feel like [with] the standards alignment...it was really easy to substitute out something that was old with something that was new. That was very easy."

To understand how teachers' knowledge and skills changed or improved, we asked teachers in the year-end interviews to talk about which of the project's curriculum and instruction components were the most important for their biology students to learn from and which component they used the most in class and why. Teachers said that learning about how to use the visualization tools to help students learn the science content was important. For example, one teacher remarked, "It's really hard for the kids to kind of visualize and understand...but a lot of them kind of had that aha or I get it now moment." Other teachers discussed how their use of scientific practices, such as argumentation, changed. One teacher stated,

So when they come to me, it's the first time that they see it. And by now, I've got most kids stating a claim, gathering evidence and understanding some difference between evidence and reasoning...and actually the thing that has helped the most this year on it, is that I am requiring all answers to questions that I ask in that framework, even if the framework isn't the greatest for the question, I am actually getting better answers from the students.

Teachers also talked about pedagogical benefits and how the project helped them to work with modeling tools effectively:

I loved the tools, the StarLogo for modeling and for visualization and simulation. It was fantastic because...a lot of times...if you said here's StarLogo, I wouldn't have had a clue on how to develop any kind of plans or lessons or inquiry based activities. So to have them start off the simulations and then to go backwards and do the modeling...[was great].

Overall, teacher interviews unanimously demonstrated interest in the project for themselves and their students. They identified four main areas of benefit for student learning: (a) student-centered scientific investigations; (b) interaction with computer models; (c) development of evidence-based reasoning skills through argumentation; and (d) multiple resources for developing complex systems understanding (e.g., models).

All 10 teachers have requested opportunities for continued involvement beyond the life of the grant, signaling strong support for the program. More concretely, in their interviews, they identified five affordances of the project related to their own learning and engagement: (a) relevant and multiple resources to engage in real content learning and pedagogical training; (b) access to expert facilitation; (c) peer sharing and collaboration; (d) numerous opportunities to develop teaching skills through hands-on participation and practice; and (e) a sense of identity and community aimed at reforming science education.

Evidence that students showed learning gains in biology and complex systems understanding

For the 14-point biology content test, student scores increased significantly from pre- to post-assessment—from a mean of 6.67 to 8.40 where F(1, 344) = 32.23, p < .001 and an effect size = .38 (Cohen's d). Students' complex systems understanding measured through the two open-ended questions also showed positive significant growth moving from a mean of 1.48 to 1.61, where F(1, 350) = 96.03, p < .001 an effect size = .39 (Cohen's d). We do not know how much of this gain would have occurred in the absence of the intervention particularly for the biology content test because we did not have a comparison group. We are also aware that the actual gains in their scores on both measures were relatively small. However, we believe that the moderate significant gains in effect sizes are encouraging results especially for complex systems understanding as the curriculum was new to students and teachers.

From student focus group interviews, several themes emerged that demonstrate the utility of the project activities and curricula to support the development of complex systems understanding. Almost all students mentioned the affordances of interactivity, repeatability, student-centeredness, and visualizations of the simulations. The more interesting ideas in the interviews came in the form of students' abilities to transfer knowledge of complex systems to explain other phenomenon. For example, one student states:

Well I think they're trying to say everyone or every living thing has a part, and the parts interact as we have like kind of a system. Everyone has their own initiative of what they are trying to accomplish or do, or how they work. Then everything working together creates one thing or not even just one thing. It has a lot of different effects in their own ways.

Here the student makes inferences about the general nature of systems that she gleaned from her participation in the project's collective learning activities. She later states:

Well every time we did a lab it was like saying - the one about the lactose...you had one part that started something, but connected to another part, and all of these parts connecting made up the system that did one thing. Every part was programmed to move a certain thing or have this one objective, but all combined they did one overall thing that wasn't necessarily what each part did.

This student is articulating the complex systems ideas of emergence, self-organization, and scale, which are essential components of complex systems understanding.

Discussion

Education has become ripe with policy, scholarship, and resources to support the study of complex systems. For example, all seven of the crosscutting concepts in the new NGSS reflect important aspects of complex systems such as *Scale*, and *Structure and Function*. This has raised challenges for educators who must follow the NGSS alongside other contextual and professional demands. Thus, understanding optimal methods for constructing educational experiences is critical. Equally important in this effort is focusing on teacher change, their role in adopting these reforms, and how they can be further supported in the classroom.

Although a good deal of research has been conducted in K12 science education on various complex systems-related topics, surprisingly few frameworks and studies have considered teaching contexts and teachers. In this paper, we introduced a framework for teaching and learning about complex systems that addressed needs in designing approaches for classroom implementation and teacher change in addition to designing activities for student learning. Working closely in PD activities with our teachers, we gathered information about whether their instructional practices changed and investigated reasons for how and why they changed. The results indicated that teachers used more computers and simulations and also increased the use of scientific practices in their instruction. They identified several affordances of the project's design in supporting their own learning, which included relevant and multiple resources, peer sharing, and hands-on participation and practice. Student learning in both biology and complex systems content significantly improved and teachers collectively said that project resources were useful to them in their classroom practice. However, in interviews, teachers said that they themselves learned about complex systems but acknowledged that they needed more time to learn how to reinforce the ideas in their lessons. Teachers discussed a similar need for more time to become pedagogically confident about programming the StarLogo simulations and, for some teachers, fully implementing the argumentation process. We continued to work with teachers to develop more resources to help them teach in these three areas. Teachers also shared their teaching strategies with each other in Saturday PD sessions during the school year. Teachers told us that these opportunities to continue practicing integrating the ideas into their instruction, to access more resources, and to learn from other teachers were invaluable to their growth.

As we move forward in adopting and translating the NGSS into classroom experiences, the teacher's knowledge, skills, and attitudes will be crucial to successful implementation. Working as research and design collaborators with us, teachers provide invaluable feedback about their perceptions of the utility of the resources and the value added to instruction. Importantly, they provide essential information about how to improve the design based on their professional and contextual expertise, which we must incorporate into future implementation iterations if reforms are to take a hold in the science classroom. We believe that the significance of this study lies not only in articulating design features that work in concert with each other to improve student learning and teacher instructional outcomes but also in examining teachers as the recipients of these complex systems reforms which research has yet to seriously investigate apart from one or two studies (e.g., Randler & Bogner, 2009).

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A Long-Term View on Learning to Argue in Facebook: The Effects of Group Awareness Tools and Argumentation Scripts

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Abstract: Social networking sites pose a new arena for argumentative practices and may provide an opportunity to facilitate, and understand argumentative processes in large scale over longer periods of time. Through apps, group awareness tools and argumentation scripts can be implemented in social networking sites, to provide additional, graphically visualized information, and prompt learners to formulate or review sound arguments. This 2×2 field study (N=105) examines how Facebook can be harnessed for argumentative learning through group awareness tools and argumentative knowledge construction and attitude change. The results show a main effect for both conditions on domain-specific knowledge and argumentative knowledge construction, but no difference to the control group on attitude change. The epistemic quality and formal quality increased for the groups with argumentation script. All observed changes become substantial after the fourth week of interactions.

Keywords: argumentation, group awareness, scripts, social networking sites, long-term study

Argumentative knowledge construction in social networking sites

Social networking sites (SNS) afford collaborative processes that may be harnessed for learning (Greenhow, 2008; Greenhow & Robelia, 2009). SNS may offer a rich argumentative context that can pronounce processes of argumentative knowledge construction (AKC). AKC is the deliberate practice of elaborating learning material and discussion topics by constructing formally and semantically sound arguments with the goal of gaining argumentative and domain-specific knowledge (Andriessen, 2006). With SNS being prone to trivial talk, AKC in SNS may greatly benefit from instructional approaches of CSCL (Tsovaltzi, Puhl, Judele & Weinberger, 2014; Tsovaltzi, Judele, Puhl & Weinberger, in review). Moreover, recent research has revealed that while argumentation skills can be fostered by controlled short-term technology-enhanced instructional approaches, no substantial effects on domain-specific knowledge can be attained with these approaches (Wecker & Fischer, 2014). One reason could be that complex and meaningful learning such as argumentative learning takes time (Reimann, Utz, Unterberger & Halb, 2014). Long-term interventions have been suggested before to successfully foster argumentation skills with young adolescents (Kuhn & Crowell, 2011). However, existing approaches have often been too coercive for learners to actively regulate their individual or group AKC processes (Dillenbourg, 2002), and others might be too subtle to have an effect on learners' self-regulation or the coregulation of the group (Phielix, Prins & Kirschner, 2010). Can SNS, like Facebook, productively host argumentative knowledge construction? How can the combination of rather coercive scripts, and less coercive group awareness tools (GATs), foster the development of learners' AKC?

Argumentation scripts

Argumentation scripts are a prominent approach to foster AKC in CSCL environments (Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012). *Scripts* are socio-cognitive structures that specify learners' interactions in collaborative learning scenarios, aiming to either activate existing internal scripts, organize, or re-organize internally represented pieces of information, mostly declarative, that may constitute new elements of scripts (Fischer, Kollar, Stegmann & Wecker, 2013). Internal scripts are already represented in the learners' cognitive system that are prone to change and adaptation. External scripts suggest collaborative processes and can change the learners' behavior over time through internalization (Kollar, Fischer & Slotta, 2007). In terms of collaborative argumentation processes, the internalization of an external script can guide learners to structure, discuss about, and reflect on their arguments, which can foster knowledge co-construction, argumentative and domain-specific knowledge (Weinberger, Stegmann & Fischer, 2010), and structure students' discussion of conflicting opinions (Jermann & Dillenbourg, 1999; Felton & Kuhn, 2001). In the ArgueGraph script (Jermann & Dillenbourg, 1999; Kelton & Kuhn, 2001). In the KraueGraph script (Jermann & Dillenbourg, 1999, Kelton & Kuhn, 2001).

2007), differences in opinions on seminar topics where represented to the students in order to increase sociocognitive conflict. Students were then asked to resolve these differences in dyads and reach an agreement by writing arguments derived for their learning materials. Discourse analysis showed that students often provided conditional responses, in accordance with the high-order learning goal of the course.

Group awareness tools

GATs are used in CSCL scenarios to enhance collaboration processes and also to foster domain-specific knowledge by giving students information about other learners, such as individual knowledge (Janssen & Bodemer, 2013). GATs can reveal inconsistent knowledge or differences of views and thus enhance controversial CSCL discussions, and impact group processes, like socio-emotional and motivational processes that are meant to support AKC (Buder & Bodemer, 2008). GATs also make group processes or attitudes explicit, for instance by visualizing how learners evaluate their own and the group's cognitive and social interactions (Phielix, Prins, Kirschner, Erkens, & Jaspers, 2011). Group awareness of knowledge distribution in the group has been shown to counteract negative effects of overly high levels of both mutual trust and mutual skepticism (Engelmann, Kolodziej, & Hesse, 2014). Moreover, GATs have been shown to enable group processes that may support knowledge co-construction, like mutual modelling, (Sangin, Molinari, Nüssli & Dillenbourg, 2011), and group conflict (Phielix, Prins & Kirschner, 2010). There are first indications of positive effects of GATs on learning gains (Sangin et al., 2011). In particular, GATs that visualized cognitive conflict in the form of discrepancies in the group solutions (Bodemer, 2011) or of summary of anonymous opinions (Buder & Bodemer, 2008) have been found to enable collaborative discussion of conflicting perspectives, foster individual learning gains, and increase critical argument elaboration during collaboration, as well as individual and group attitude change. GATs are positively related to performance and process satisfaction (Phielix et al, 2010) and can prove particularly useful for learning in SNS such as Facebook to help group members consider the distribution of knowledge and attitudes, spot their own positions in relation to other members. Such group awareness may foster socio-cognitive conflict, in the sense of social tensions (e.g., why is my position different to others?) and personal dissonance (e.g., how can I bridge two contradicting views?).

Attitude change

Attitude change has been investigated in the context of argumentative knowledge construction in young students (Kuhn, Shaw,&Felton, 1997), showing a tendency to more stable positions with increasing age, and in computer-mediated communication, revealing lack of readiness to consider alternative perspectives when attitude markers are salient (Sassenberg & Boos, 2003). Argumentative processes, like taking into account multiple perspectives and resolving conflicting opinions appear to facilitate attitude change (Eagly & Chaiken, 1995; Erber, Hodges, & Wilson, 1993) and may ultimately lead learners to re-consider initial standpoints (Tsovaltzi et al., 2013). Moreover, vocational training includes practicing attitude and communication at the work place (Nasir, 2002), e.g. for medical doctors (Caralis & Hammond, 1992) and teachers (Ihmeideh & Alomari, 2010). Theory on attitude change supports that change is the result of dissonance that can be caused by cognitive conflict between different attitudes of the same person (Eagly & Chaiken, 1995; Erber, Hodges, & Wilson, 1993). Such conflicts could potentially be made salient with GATs and productively resolved with scripts. GATs may contribute to making learners' ideas, misconceptions, and contradictions accessible to scrutiny (Nussbaum, 2008). Scripts have been found to effectively specify and support how learners jointly argue to address conflicts (Weinberger et al., 2010).

We investigate the effects of a GAT and argumentation script on domain-specific learning outcomes, learning processes, and attitude change. We conjecture that the GAT will induce socio-cognitive conflict and will translate into argumentative processes. We also conjecture that the argumentation script will foster the quality of arguments in the discussion. Therefore, they will both increase the domain-specific learning gains. The combination of both factors will interact in a positive way. We also hypothesize a positive effect of the GAT on attitude change.

Methods

We conducted a 2×2 quasi-experimental field-study with German teacher trainees (*N*=105) and factors GAT and argumentation script. Participants were taking part in a seminar on "Communication and Interaction". In the intervention, all participants attended weekly seminars where a new theory on communication was presented and discussed. After the seminar, the students had to fill out a questionnaire about their communication attitude. Seminar groups were accompanied by Facebook groups, where students weekly received a theory-related task that required them to interact and discuss online within five days. The study was part of the seminar and lasted the whole semester. Students had to fill out the communication attitude questionnaire on nine sessions and were

instructed to reflect on the seminar theories while filling in the questionnaire. On eight sessions, an argumentation script was given as feedback to the quality of the written arguments.

Before the intervention all participants took a knowledge pre-test, and filled in a questionnaire on socio-demographic data, subjective knowledge in the domain "Communication and Interaction", computer and Facebook use behavior. In addition they filled in a communication attitude questionnaire and the experimental conditions were familiarized with the GAT. Similarly, after the intervention at the end of the semester, all participants took a knowledge post-test and filled in another questionnaire on their subjective learning gains and their acceptance of the learning environment.

Group awareness tool

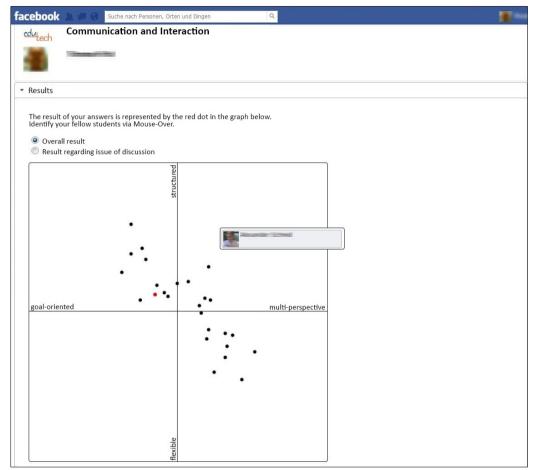


Figure 1. Group awareness tool in Facebook

Students receiving GAT-based support reflected on their hypothetical personal communication attitude as a teacher by answering a case-based communication questionnaire with cases from every-day social interactions in the school. Every scenario was followed by four Likert-scaled answers, focusing on how a teacher may reflect on and behave in the situation. Moreover, the questions differed with respect to whether the emphasis was on multi-perspective / flexible attitudes vs. goal-oriented / structured attitudes, following Buder & Bodemer (2008) and Jermann & Dillenbourg (1999, 2002), both rated on a scale from 0 to 6. The result of the questionnaire was presented to the experimental groups with a GAT implemented as a Facebook app. The app graphically visualized the position of a student with respect to the position attitude in relation to other students. The position in the graphic is represented as relative to the position of the whole seminar group (I vs. the others). The GAT also gave them the opportunity to identify the person behind a position by moving the mouse over the point on the graphic to see the name and a photo of the person (Figure 1), so the discussions were not anonymous. The design of the GAT is oriented on the ArgueGraph script (Jermann & Dillenbourg, 1999) and aims at increasing socio-cognitive conflict. ArgueGraph was adjusted to the Facebook learning environment. That is, considering the Facebook dynamic, which means frequent interactions in the large group and less

discursive discussions compared to a small group CSCL scenario, we used a less coercive instruction and did not force the students to reach an agreement.

Argumentation script

Students in the condition with script-based support received a weekly argumentation script in the form of feedback to arguments posted in the Facebook group discussion. They had to read all arguments of the discussion and "like" the best argument in their own opinion. Feedback was given to every group for the most liked argument and also for the best argument in the opinion of the teacher. The feedback to these two arguments evaluated the epistemic (theoretical concepts and relations) and the formal (reasoning and evidence) quality of arguments for the two selected arguments. It also indicated whether an important part of the argument was missing or illustrated how a sound argument should look like. While the structure and the ontology of the script were standardized, it was also important to adapt the script to the different weekly tasks and the different arguments from each group.

Instruments

Domain-specific knowledge was assessed by a course exam at the end of the semester containing definitions, facts, and higher order discursive processes like theory-based interpretations and argumentations. The knowledge test included 10 multiple choice items and 13 open questions with a high inter-rater reliability k=.88, p=000. The internal consistency of the knowledge test was good ($\alpha = .69$).

Process analysis was based on Weinberger & Fischer (2006) on multi-level analysis of AKC processes and on an adapted version for argumentation in Facebook (Tsovaltzi, Judele, Puhl & Weinberger, 2014). We measured epistemic and formal quality of arguments. The formal quality of arguments (k=.80, p=000) was measured by the correct formal structure of the argument (e.g. if justifications were used for every argument), the quality of the justification and the quality of the reference. We evaluated the quality of justifications by giving a score of three points for references to scientific results, two points for examples that may be used to explain the content of an argument, and one point for every-day knowledge that provides some potential insight but without scientific evidence. The actual citation of references was evaluated in addition to the justification. The quality of references was rated with two for a scientific reference (e.g. journal paper) and one for a link to a relevant internet site (e.g. wikipedia). The *epistemic quality* (k=.76, p=000) was measured by the quality of the used concepts or theories and the relations between them. We evaluated the quality of theories advocated in the arguments by giving a score of three points for a related theory to the discussed topic, which is the theory/theories of the week, two for using the theory of the current week, and one for subjective theories that have no scientific background. A relation drawn between current and other theories was also rated with three and added to the overall score for epistemic quality. The posts from the second seminar sessions in the Facebook group were not analyzed because of a different weekly task. The students were given a task to reflect on nonverbal communication and post a personal experience they had in this week. Therefore there was no discussion in this week and no arguments to analyze.

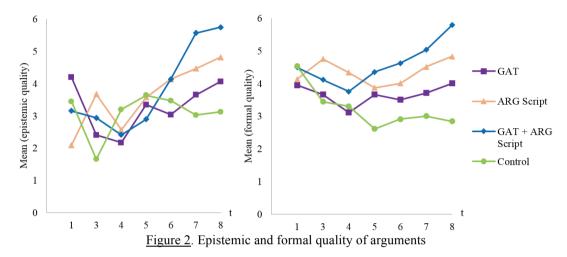
Communication attitude change was measured using the results of the communication questionnaire. The questionnaire was based on the *situation assessment test for consulting* (Keller, Bruder & Schmitz, 2010) and used scenarios to assess the communication attitudes of the participants. Contrary to the elaborated scenarios in the consulting questionnaire, the scenarios in the communication attitude questionnaire are concise for students to fill in on a weekly basis. Students were asked to reflect on the communication situations in the questionnaire and indicate how they would behave as teachers in the sketched situations. For example, a scenario presented the situation in which most of the students failed in a test. The teacher could either handle this situation by simply ascertaining that they did not study enough, or by discussing with them what they thought was the problem. Furthermore the teacher could offer to repeat the test, or discuss different possibilities with the students such as repeating the test or talking about the situation with the school principle. There are no correct answers to the questionnaire, but different theories from the ones taught in the seminar could support the different options (Puhl, Tsovaltzi & Weinberger, in press). Students expressed their attitude by indicating their agreement on the Likert scale described in the Section Group Awareness Tool.

Findings

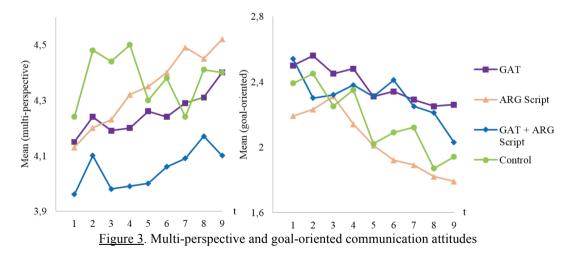
There were no significant differences in the socio-demographic data, the Facebook use and the knowledge test prior to the intervention. Log data confirmed that all participants spent time looking at the graph as an indication of reflecting upon it.

Process analysis

Using an ANOVA with repeated measures (sessions 1 and 3-8), the process analysis showed a significant effect for the interaction between time and epistemic quality, F(6;606)=3.81; p<.001; $\eta_p^2=.10$, and between time and formal quality, F(6;606)=1.88; p=.015; $\eta_p^2=.053$. Descriptive statistics also show that the epistemic quality did not change in the control group throughout the semester but increased for both groups with argumentation script. The formal quality also only increased for argumentation script and decreased for the control group (Figure 2).



To identify when the argumentative processes took shifted, we did simple contrasts comparing each session from the 3rd to the 8th time with the first session. On the epistemic dimension we found a decrease for three groups from the first time of measurement to the third. Only the experimental group with argumentation script increased the epistemic quality of their arguments. Until the fifth time of measurement all groups are close together and simple contrasts were not significant. Substantial and significant changes occurred from the first to the sixth time of measurement, F(3;101)=5.70; p=.001; $\eta_p^2=.15$, and all contrasts are significant until the end of the interventions. A similar process was observed on the formal quality of arguments. Descriptive statistics show that all groups are close until the fourth time of measurement, after that they diverged and simple contrasts are only significant between the first and the last time of measurement, F(3;101)=5.98; p=.001; $\eta_p^2=.15$.



Using an ANOVA with repeated measures, we found significant main effects on communication attitude change over the seminar period for both multi-perspective, F(8;800)=2.98; p=.003; $\eta_p^2=.03$ and goal-oriented dimensions, F(8;800)=14.2; p<.001; $\eta_p^2=.12$, but no significant effect for the interaction between time and group. Descriptive statistics also showed that attitudes increase on the multi-perspective dimension for the experimental groups and independent from the groups. Simple contrasts showed a significant main effect for the factor time from the first date of measurement to the second, F(3;100)=4.33; p=.04; $\eta_p^2=.04$, and also the changes from date one to eight and one to nine are significant, F(3;100)=5.38; p=.004; $\eta_p^2=.08$ (Figure 3). The

attitudes decrease on the goal-oriented dimension for all groups and simple contrasts are significant for the factor time as of the fifth time of measurement until the last date, F(3;100)=16.58; p=.000; $\eta_p^{-2}=.25$.

Knowledge outcomes

We found a significant effect for the experimental groups in domain-specific learning gains, F(3;102)=11.11; p<.001; $\eta_p^2=.25$. Three participants did not take part in the final exam. The descriptive statistics show an increase in learning gains from the control group to the experimental groups (Table 1).

Table 1: Domain-s	necific knowleds	e mean and	l standard	deviation

Group	Control	GAT	ARG-Script	GAT+ARG-Script
	(n=19)	(n=29)	(n=29)	(n=25)
M (SD)	34.08 (6.53)	39.81 (5.42)	41.34 (4.38)	42.52 (4.33)

Besides significant main effects for the two factors (GAT: F(1;98)=11.24, p=.001, $\eta_p^2=.10$; Argumentation script: F(1;98)=23.44, p=.000, $\eta_p^2=.19$), we also found a significant effect for the interaction between GAT and argumentation script, F(3;102)=4.89; p=.029; $\eta_p^2=.05$. The factor argumentation script shows higher learning gains (Figure 4).

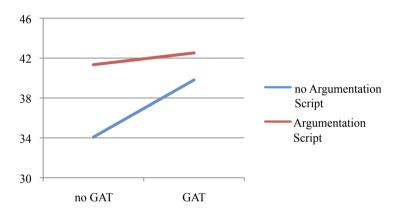


Figure 4. Domain-specific knowledge

The epistemic quality of arguments from the last time interval correlates with domain-specific knowledge r(102)=.24, p<.05, and formal quality of arguments also correlates with domain-specific knowledge r(102)=.29, p<.01. Correlations between communication attitudes and learning outcomes are not significant.

Conclusions and implications

As hypothesized, the GAT and the script guided learners to acquire more domain-specific knowledge and improved learners' quality of arguments. The argumentation script seems to outperform the GAT with respect to both of these variables. The combination of both instructional approaches shows the best results on all variables. Notably, the effect of GAT and script on the quality of arguments seems to set in only after 4-5 weeks of the seminar, indicating that it takes time to develop strategies for building high quality arguments and respective knowledge. By the same token, it may be very difficult in short-term interventions to raise quality of arguments and even more difficult to increase domain-specific knowledge (Wecker & Fischer, 2014). It has been argued that learners are overwhelmed in short-term learning environments to consider both, the quality of arguments and acquire domain-specific knowledge. Long-term interventions, in contrast, can realize AKC that facilitates both, argumentative and domain knowledge. Consequently, the relation between AKC processes and outcomes appears to develop over time.

Learners' attitudes shifted on the multi-perspective dimension after the first seminar week from the baseline to the second measurement time. Since the first intervention took place after the second measurement time, the change from first to second time cannot depend on the two factors, but rather on the content of the seminar. The communication theories from the first session specifically address the multi-perceptivity of understanding messages and the students were always instructed to reflect on the seminar theories while filling out the communication attitude questionnaire. Over the entire seminar period, all experimental groups incl.

control group developed on the multi-perspective dimension. All groups declined on the goal-oriented dimension over time. While these attitude changes may derive from the seminar theories independent of GAT or script, it goes to show that learning and attitude change are not linear processes. Over the seminar period there were no significant differences between the groups, which is contrary to prior findings showing that groups with higher coercion awareness tools surpassed groups with lower coercion awareness tools (Puhl et al., in review). This potentially means that interventions of group awareness and higher coercion (e.g. scripts that prompt learner's to reflect on the visualized group awareness revealing conflictual ideas and attitudes) can rather influence attitudes.

This study extended CSCL research on scripts and group awareness tools to SNS. It thus provided insights into long-term effects of these instructional approaches of CSCL. While these approaches do not produce the expected short-term effects on domain-specific knowledge (Wecker & Fischer, 2014), this study shows that such effects can still emerge in the long run.

In contrast to popular views, SNS can serve as a platform for argumentation and learning. The results in this study reveal that learning to argue may take a social environment, in which groups develop shared argumentative practices over time. SNS may offer themselves as such an environment. Two main directions may be taken from here. First, SNS can host long-term studies that can contribute to understanding and facilitating argumentative learning in social communities. Second, massively used online fora like SNS offer the possibility for technological interventions such as the ones investigated here. SNS may be leveraged to develop practices of argumentation on a large scale.

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Beyond Pedagogical Challenges: Addressing the Social Aspects around the Use of Digital Resources in University Education

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Abstract: This article presents the results of a qualitative study in which the challenges of adopting and adapting digital media to the context of higher education were investigated. A workshop attended by university teachers and professional producers of educational video material was organized. The analysis draws attention to issues concerning the quality of digital media, the development of the professional skills required to produce and use them, and the orchestration of learning activities centered on such learning resources. The paper argues that understanding the challenges around the appropriation of digital media in educational settings encompasses the social and contextual aspects of the settings in which technology is to be used, and not merely the pedagogical concerns underlying its usage.

Keywords: Qualitative studies, digital resources, teaching-learning practices

Introduction

This paper draws attention to the challenges inherent in the adoption and appropriation of digital resources in higher educational settings. Whereas previous research within the fields of Computer-Supported and Technology-Enhanced learning has mostly focused on the pedagogical aspects of educational technologies (Zhao & Frank, 2003; Selwyn 2007), this paper discusses the social and contextual aspects related to their adoption and use. We argue that a focus on the social aspects, and on the teachers personal experience of using digital resources and technology is relevant to CSCL research as it fleshes out the conditions that can become the material barriers hindering their actual appropriation into teaching practices.

Technological development has contributed to the emergence of an information society, where economical and cultural aspects are intrinsically changed by the permeation of ICT (Castells, 1996). Education is certainly not an exception to this global trend. Interactive technologies have, in fact, become central actors in contemporary educational practices, and in the current discourse on how national educational systems can be improved by the introduction of digital technologies and platforms. This is also reflected in the large body of research focusing on: i) how technological innovation is reframing our understanding of what technologymediated educational practices entail (i.e. Dillenbourg et al., 2009; Goodyear & Retails, 2010); ii) the set of methods that can be adopted to teach and learn with technology; iii) the set of skills required to be a learner in modern societies (Oppenheimer, 2007; Kay & Greenhill 2011; Robinson 2011). For instance, a current discourse in the Learning Sciences explores the potential of Massive Open Online Courses (MOOCs) as having the potential to profoundly transform education, and to provide a solution to the economical problems contemporary educational systems are faced with (Pappano, 2012; Friedman 2013). This rhetoric and research inclination are common to most Western countries, including the one in which the study presented was carried out. An initial motivation to carry out this study was, in fact, determined by an intention to critically discuss the recent institutional demand to undergo a *digitization process* of the courses available at our department, and to adapt our teaching practices to the production and introduction of digital resources (i.e. video material). This practical intention has, in turn, been instrumental to the more general aim to problematize the abstract optimism in the effectiveness and potential of technology (i.e. Cuban 1986; Oppenheimer, 2007; Nouri et al., 2014), and to critically consider the causes for their poor integration into teaching practices (Buckinghamn & Willett, 2006; Coiro et al., 2008; Snyder et al., 2010).

The pervasiveness of the technological infrastructure in contemporary societies contributes to making digital educational recourses (i.e. MOOCs lectures, but also OpenCourseware, YouTube videos, TED Talks, Podcasts, Wikipedia), a free commodity ready to be used in the context of higher education. However, as noted (Fischer, 2014, Eisenberg & Fischer, 2014), the hype around the use of such media lacks a serious pedagogical grounding (Vardi 2012), and is often based on a too narrow focus on the mere individual learning activities favored by this type of education.

This paper seeks to extend this argument. While the aforementioned aspects are indeed essential, we argue that a critical understanding of the use and introduction of digital resources into the context of consolidated teaching-learning activities should also entail other issues – for instance, teachers' expectations,

possible challenges and advantages they might experience, their opinions on how using digital resources might impact their role as a teacher, or the expertise required to be a competent one. Although such aspects are more directly connected to the felt-like experience of using technology (McCarthy et al., 2004), rather than to effective learning outcomes, they are central, as they contribute to a more complete understanding of how interactive technologies are appropriated (Engeström et al., 1999; Dourish, 2003) in pre-existing practices, and what hindrances can emerge when they are introduced into a specific setting. As noted elsewhere (Selwyn, 2010), studies of educational technologies are often merely focused on the educational potential technologies could play in the context of novel teaching approaches (i.e. flipped classrooms, inquiry-based learning, peer-topeer learning, etc.), and how they should be used in such settings. Furthermore, these investigations are often carried out at the level of the individual teacher and learner, while overlooking organizational aspects inherent in educational institutions, or issues connected to personal, social, political or economic values of the context in which they are to be used (Zhao & Frank, 2003; Selwyn 2007). Against this background, this work discusses the challenges entailed in the adoption of digital technology in a university setting. Rather than merely focusing on the pedagogical aspects, this paper highlights the entanglement of the various challenges that various stakeholders experience with respect to the use of digital resources in higher education. More specifically, we draw on the personal experience of teachers, researchers in the field of Technology-Enhanced and Computer-Supported Learning, professional producers of educational video material, and of university staff covering managerial positions. The research presented is instrumental to a discussion on the implications that the broad availability of digital resources has for higher education against the backdrop of a global scenario in which universities are expected to quickly adjust the development of the "learning society" and ICT use (Bridges et al., 2007).

The empirical data stems from a one-day workshop conducted in October 2013. The goal of the workshop was to unpack and discuss the main limitations and advantages, hindrances and possibilities of using digital media (particularly video material) in the context of university courses, both campus- and online-based. The data analysis draws attention to the challenges related to: i) assessing the quality of the digital resources available online; ii) acquiring the skills needed to create and edit such resources, and iii) the concern to orchestrate meaningful and engaging learning activities around their use. In concluding this article, we relate our findings to three points, namely: i) the attempt to modernize pedagogy and teaching practices in an educational context that still privileges and reproduces traditional teaching modalities (i.e. teacher-centered lectures); ii) the expectations that teachers should also be producers of digital contents; iii) a reconsideration of the role of university from producers to providers of knowledge. These issues relate to the social character of the university department studied, which is regarded as a work context reflecting specific assumptions on the social organization of the teaching practices supported by technology.

Methodology

The data discussed stem from a workshop organized and held at the department the authors of this paper are affiliated with. A total of *twenty people* volunteered to participate in the workshop. All participants worked in the field of higher education, although in different roles including researchers, teachers and department managers. Five of the participants were professional producers of educational video material who worked for Sweden Educational Radio (Utbildningsradio AB), a public television broadcasting company operating at a national level. All workshop participants had previous experience with the use of digital technology to support teaching or learning practices. The workshop lasted for 3 hours and was conducted in the fall 2013.

The goal of the workshop was to collect examples regarding the use of digital resources in current teaching practices, as well as to unpack the main benefits and problems the different participants had experienced while concretely using the digital media and the interactive technologies discussed. The scope of this workshop was in line with the tradition of informing the design and development of interactive technologies by drawing on an understanding of the actual context in which such technologies are to be deployed (Huges, Randall & Shapiro, 1992; Randall, Harper & Rouncefield, 2007). The study was, therefore, instrumental to the ultimate objective to explore possible improvements to an educational system currently required by governmental policies to undergo a number of changes also with respect to technology use (David Bridges et al., 2014). Our specific focus was to investigate *how digital media, especially video material, can be a resource in the development of pedagogical quality in teaching and education.*

The workshop entailed two phases. During the first two hours, the participants were divided into two separate groups; the discussion was then facilitated by the first two authors, each one responsible for one of the groups. This round of discussion revolved around the following themes: i) how current digital media can be a resource, or a hindrance in current teaching practices; ii) the participants' expectations about education, students, colleagues, and the use of digital media, particularly video; iii) the participants' needs and concerns in

envisioning possible future use of digital resources. During the last hour of the workshop, the two groups gathered again for a common round of discussion, and to compare and exchange opinions about the main topics previously emerged. The entire workshop was video-recorded and documented by means of note-taking. All the conversational data were transcribed, and thematic analysis (Bryman, 2012) was used for the analysis. Thematic analysis is a qualitative method based on the search for themes that become prominent in the description of a certain phenomenon, or of the way people talk about it. Themes are usually identified through a recursive reading of the data collected. As themes are specified, (re)defined and grouped together, they become emerging categories of analysis.

In our case, going through the transcribed material for a first round of analysis allowed us to identify a number of themes regarding the participants' overall experience of using ICT in their teaching practices. During this phase, we fleshed out themes addressing various challenges related to the use of educational platforms, such as: respecting copyright and availability issues when providing access to digital materials, the teachers' concern to continuously develop their personal skills, and their concern to be able to share with other colleagues both best practices and recurrent problems. During a second, more in-depth analysis, we sought to triangulate the data collected within the two discussion groups in order to identify possible contradictory or overlapping issues. During this phase, we focused more explicitly on the teachers' perception of the skills that are required to produce digital resources, particularly video material, the learning activities that can be implemented around the use of such resources, and the problems related to assessing their quality.

As we will illustrate in the following sections, these themes are not solely pedagogical in nature. In fact, the pedagogical character is intertwined with, and inseparable from, a number of social and contextual aspects of the setting studied (i.e. providing teachers with the resources needed to develop their own digital literacy). Furthermore it is interwoven with the teachers' personal experience of using digital technology and media (i.e. strategies for assessing the quality of digital resources) at the very specific workplace where the teaching practices discussed were situated and enacted.

Findings

All the workshop participants involved in teaching had a positive inclination towards the adoption and use of digital media (i.e. YouTube videos, video lectures created and given at other universities, scientific articles and books, training simulations, etc.) in their teaching practices, both including on-campus teaching and distance education. Because of the inter-disciplinary nature of the department in which the study was carried out and, therefore, of the different backgrounds of the teachers present, a variety of courses was discussed during the workshop. They included topics such as Human-Computer Interaction, Digital Prototyping, Programming, Social and Behavioral Sciences, Project Management, Health informatics, etc. Despite almost all participants had encountered problems when using digital resources (i.e. assessing the quality of digital materials, having the right skills to create and produce them, making sure they are accessible over a period of time, etc.), there was a shared consensus that they should be further deployed in the context of higher education; this was regardless of the subject area being thought.

As the workshop discussion highlighted, a broad variety of digital resources is currently available online and used for different purposes. For instance, video material available on Youtube is sometimes used as inspirational material to prepare a lecture, or to provide students with additional resources to learn about a certain topic. One of the teachers mentioned, for instance, the possibility to access and use original sources, such as Skinner's lecture on behaviorism; another one referred, instead, to the use of a set of instructional videos that had been created at the department to give students practical guidance to manage the process of writing bachelor theses. As it was discussed, accessing this large body of digital contents does not constitute a serious problem, either for the teachers or the students. The various challenges the teachers pointed out were, instead, related to the actual use of such resources – for instance, being able to actually develop and create digital materials, how to design meaningful teaching-learning activities around them, as well as more societal questions on how their usage could possibly redefine the role of university at large.

The following analysis has been organized around three themes that further specify these main challenges, namely: assessing the quality of digital resources, developing the new set of skills needed to produce them, and orchestrating learning activities around their use.

Assessing the quality of digital resources

One of the challenges emerged during the analysis concerns the quality of digital resources. The nexus of this point is that the large availability and accessibility of digital media makes it challenging to search for and select the ones that are considered as suitable to a specific topic. As a number of participants pointed out, it can be problematic to assess the quality of a resource such as a video, or a short clip. This aspect of selecting

educational resources was experienced as considerably more straightforward with more traditional published media, such as books or scientific articles. This was especially true when such references are key readings within a certain scientific area, or have been written by authors who are central within a certain field. Thus, as knowledge becomes a commodity scattered across the main information infrastructure that is the Internet, it becomes time consuming to look for it, and challenging to assess how suitable it is for certain educational purposes, unless it is thoroughly scrutinized and assessed.

Another problematic aspect related to the quality of digital resources concerns the possibility to adapt the contents to different knowledge and expertise levels, especially when such resources have been created for very specific educational purposes and subject-areas. For instance, one of the participants, who had a long teaching experience in the field of health informatics, considered simulation software for training medicine students inflexible. As it was explained, such systems have been developed in order to convey specific set of contents and to develop specific skills, which can make it problematic to adapt them to the context of a specific course. This, in turn, constitutes a serious hindrance if such resources do not completely match a teacher's perspective on a certain topic, or if their quality is not entirely suitable for the level of a course. This challenge was discussed by both groups of participants, also with respect to different type of courses. For instance, a teacher working with an online course on Project Management explained that while planning one of his courses, he had found a large body of YouTube videos providing good guidelines on managing projects. Nevertheless, the contents entailed so much more than what they wanted the students to work with that, eventually, they had to create their own instructional video material which was eventually distributed to the students on YouTube.

This issue of quality was also a practical concern for the professionals working at the broadcasting company, who usually seek to account for the quality of the material they produce by explicitly presenting the reasons for choosing certain speakers, and how representative they are of a certain topic.

Acquiring and developing a new set of skills

A second main concern emerging from the workshop discussion relates to the novel set of skills that the participants, especially the teachers, felt were required in order to self-produce educational digital resources. In fact, differently from the more traditional situation of choosing printed literature for a course, most of the participants perceived as an organizational demand the fact that they would have to become more directly involved in the actual creation of digital resources, particularly video material. As several of them emphasized, being able to produce digital materials requires the development and acquisition of an expertise, which the participants felt they were not trained for.

The discussion around such a competence embodies two main issues that were tackled during the workshop. On the one hand, this competence entails the technical expertise of being able to create and edit digital materials. As one of the participants complained, this expertise is seldom used, and most of the oncampus lectures currently video-recorded are just uploaded to the university video-player platform without further editing. Moreover, in most cases, they reflect the interaction modalities of a "traditional" lecture in which the teacher plays the central active role of creating contents and delivering them. On the other hand, this discussion connects to other concerns, such as the need to re-think pedagogical approaches (see the following section), and to *support teachers in the development of narrative skills* that are more suitable for video-mediated lectures rather than face-to-face ones. As one of the participants put it:

"One of the concerns I have is that I think I should change my way to prepare a lecture when I'm thinking to include a video. [the thing] is that I have to tell a story to the students, not only to go through the contents as I used to. And the structure is a bit different. Including a video then I have to try to be consistent with the video and transform the lecture into telling them a story". (Livia).

As the quote indicates, including a video into certain teaching practices requires a different structure and a type of narrative that is more suitable to the way a video-mediated story is told. As this participant further explained, acquiring these skills encompasses a transition phase needed in order to change practices. This point raised an intense discussion during the workshop, as personal concerns relating to pedagogical approaches and professional expertise became intertwined with the organizational concern of managing resources at the department. For instance, the participant who also worked in a managerial position explained that there is no economical possibility to allocate the resources (i.e. time) teachers would need to acquire the skills required to become different types of storytellers. This types of competences constitutes instead a job for a different professional role altogether. As he put it:

"I can stand in front of a camera and talk and probably say something reasonable, but I could never produce it, I could never edit it, [I could never] work with the sound cause I don't know how to do it. This is a job for a person each" (Jamie).

Orchestrating learning activities centered on the use of digital materials

The discussion around the quality and relevance of video material was interwoven with a reflection on the teaching-learning activities that can be designed around the use of digital resources. As most of the participants emphasized, considering the use of digital resources for teaching entails also a reflection on the active role that teachers play in providing a context and a structure for those resources. This point was extensively discussed, probably because the presence of both the teachers and the professional content producers contributed to a dialogue where two different points of view complemented each other. This central concern to focus on teaching activities mediated by the use of digital resources evolved alongside two main issues.

On the one hand, the participants drew attention to aspects of students' motivation, and to some research studies arguing that the current organization of university courses is a source of a very low motivation level for students (Jim Eales et al., 2002; Schoor & Bannert 2011). As one of the participants strongly believed, a way to overcome motivational problems would be to invest in the production of digital resources, and then to use them in the context of well-structured courses and assignments providing the students with a clear and explicit idea of what is expected from them. As he put it:

"Teachers' competence is about giving a structure, to create order in this media storm" (Jamie).

This point also sparked an intense discussion on more societal issues, such as the future of higher education. The availability and permeation of digital media in the context of higher education (the "media storm" mentioned in the quote above) is changing the vision and the expectations on the role of university in contemporary western societies. Since a growing number of content providers and universities are extensively investing in MOOCs, it is plausible that the teachers' role in the future could be limited to being examiners, and to making sure that certain learning goals have been achieved. This is of course a controversial argument one could either agree or disagree with. Nevertheless, it is interesting to note that it resonates with the body of technology-centered literature characterizing the current discourse on MOOCs and the positive expectations they are invested with (see Vardi, 2012; Fischer, 2014 for a critical view on this point).

On the other hand, the discussion on using digital resources in the context of teaching practices evolved around the pedagogical approaches that were considered more adequate. One suggestion was, for instance, to more extensively adopt flipped classrooms approaches in order to be able to actually discuss the contents delivered and shared. Educational psychologists like Bruner (1996) have contended the importance to present learners with contradictions in order to stimulate critical thinking and reflection. Likewise, during the workshop it was emphasized that one of the most interesting aspects of teaching is to be able to establish a discussion around the learning material used. Finding good questions triggering relevant discussions was considered central to reflect on the different perspectives that might exist around a certain topic, even when they are not completely in accordance with a teacher's opinion.

This discussion also raised a number of other concerns more related to the department seen as a complex and social workplace. When discussing the actual use of digital media, such issues become entangled with the pedagogical challenges inherent in orchestrating learning activities based on the digital resources in question. One such concern was, for instance, managing teaching resources in the context of large courses. As it was noted, the flipped classrooms approach is based on the idea of discussing and using (pre)acquired knowledge in a classroom context under the tuition of a more expert teacher; as such, this approach is already underlying a number of classroom activities (i.e. seminars) in which students are first required to read, and then to play an active role in engaging with knowledge and working with it. As experience shows, this is more easily achieved in small courses, rather than the ones attended by three-hundred students, a case which is quite common at the department were the study presented was carried out.

Discussion

The goal of the study presented was to unpack the challenges that teachers and other professionals involved in the field of university education experience as connected to the adoption and use of digital resources. The themes chosen have drawn attention to the teachers' concerns regarding: i) the quality of digital media, and how to assess it; ii) the importance to acquire and develop narrative skills that differ from the ones needed to prepare and deliver traditional face-to-face lectures; iii) the lack of economical resources to be devoted to this type of

training; iv) how the extensive availability of digital resources, created by heterogeneous content providers, is eventually connected to the societal role of universities, from creating knowledge to merely delivering it. Considered together, these themes reflect a number of pedagogical issues emerging from the use of digital resources, but also the individual, the social and organizational concerns (i.e. allocation of economical resources) that can become material barriers to the introduction of digital technologies. These aspects, we argue, come to the fore when the broader social setting in which digital resources and technologies are to be used is accounted for (Barkhuus and Lecusay R., 2012; Huge, Randall & Shapiro, 1992; Selwyn, 2007 and 2010). In what follows we further elaborate on the findings presented while discussing them with respect to the current discourse on the use of digital resources in higher education.

Firstly, the analysis reveals a tension between a concern to change and "modernize" current pedagogy, and the consolidated organizational practices that are reproduced in the way education is managed at a department level, and instantiated in the single courses. Scholars have noted (Dillenbourg, 2009; Andersen & Ponti, 2014; Fischer, 2014) that research in the Learning Science and technology-mediated learning have emphasized the importance: i) of self-directed learning, peer-to-peer learning, flipped classroom approaches, etc; ii) and to explore how these novel pedagogical approaches can capitalize on the use of interactive and digital technologies. Nevertheless, academic teaching is still based on the traditional idea of teacher-based teaching (Fischer, 2014), and this was also reflected on the expectations that many workshop participants had with respect to the integration of digital media into their teaching practices. In other words, this seems to be an attempt to change pedagogy, and teaching-learning activities in an organizational framework that reproduces and encourages traditional classroom lectures. Administrative and teaching routines, as well as support structures (allocation of time and other resources) are, in fact, based on the assumption that a single teacher is responsible for managing a course, giving lectures, and designing examination modalities. During the workshop, for instance, one of the employees from the broadcasting company - and therefore somebody external to the department context - pointed out the absence of any internal collaboration between teachers to share best practices and examples of using digital media at the department.

Secondly, the workshop revealed an implicit expectation that teachers should also be producers of digital contents and materials. Certainly, one could argue that teachers are always producing new teaching material (i.e. lectures, course compendia, exercises, tutorials, etc.). Nevertheless, in this case there seemed to be a shared assumption that whether a book can just be used, a digital resource must be created anew or edited in order to be used effectively within a certain course. One reason explaining this could be that for some teachers it is important to feel empowered and competent by producing their own material (i.e. lectures), rather than using what is already available (i.e. a video lecture). However, we argue that on a more general level this reflects aspects of how people enact and reproduce social and cultural phenomena by means of technology, particularly the values and meanings that can emerge when people use certain interactive artifacts (Friedman, 1997). In the case addressed, this entails various expertise and competences that the teachers thought they should have. As we have seen in the analysis, this includes the pedagogical and technical skills needed to be able to create meaningful digital materials and to edit them. Ultimately, we argue, this reflects on the perception of what constitutes a central expertise to be a skilled teacher.

Finally, a related issue stemming from the analysis concerns a *reconsideration of the role of universities in western societies*, more focused on delivering and communicating knowledge rather than producing it. Technologies are never neutral, and they profoundly modify the activities and the context in which they are used (Haas 1996; Engeström, 1999). On an obvious level, this becomes materialized, for instance, as the social impact of technology effecting both the individual and the collaborative practices enacted in a certain setting (i.e. the way a certain activity unfolds). However, these changes become also manifest at the level of the political and societal expectations and beliefs concerning the transition that is foreseen and promoted for higher education. Phenomena like MOOCs, and the debate connected to the extensive availability of digital resources can all be framed in the broader context of globalization, knowledge economy (Smith, 2007; David Bridges et al. 2007), and of how economical and cultural aspects of society are redefined by the pervasiveness of ICT (Castells, 1996). All these aspects become entangled in the discussion on how interactive technology and digital media can and should be used in higher education. This, in turn, contributes to the emergence of new possibilities for the production and circulation of knowledge where, as noted (Etzkowitz & Viale, 2010), the university transition into the 21st century is driven by a concern to make knowledge available across various contexts.

Conclusions and implications

In this paper we have introduced the findings stemming from a one-day workshop that was organized in order to discuss the use of digital media in higher education, and how they can be experienced either as hindrance or as

an opportunity for current teaching-learning activities. A total of twenty people participated in the workshop, and they included teachers, researchers in the field of Technology-Enhanced Learning, professional producers of video material for educational purposes, as well as department staff in managerial positions.

The data analysis has illustrated the pedagogical aspects entailed in orchestrating engaging learning activities centered on the use of digital resources. Furthermore, it has shed light on the social and material aspects connected to the use of digital resources in a university context. More specifically, the teachers' experience of how the adoption of such resources relates to the expertise required to use such resources and, thus, the redefinition of what it means to be a competent teacher.

The analysis presented is relevant as it is instrumental to a more general discussion on the implications that the extensive availability of digital resources, and the transformation of knowledge into a commodity has for higher education. With this regard, we have tackled three main issue, namely: i) the attempt to modernize pedagogy and teaching practices in an educational context that still privileges and reproduces traditional teaching modalities (i.e. teacher-centered lectures); ii) the expectations that teachers should also be producers of digital contents; iii) a reconsideration of the role of university from producers to providers of knowledge.

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Constructing Knowledge: A Community of Practice Framework for Evaluation in the VMT Project

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Abstract: This paper describes a formative evaluation of the Virtual Math Teams (VMT) Project as it adopts the GeoGebra dynamic-mathematics application. The project team is considered as a Community of Practice, which communicates with student users through boundary objects. An ethnographic action research approach is used to analyze three sources of data: VMT user manuals; screenshots of tool interfaces and assignments; and logs of student chat sessions addressing those assignments. The analysis focuses on how the topic of 'construction' is articulated in each data set. The results show that the team understands 'construction' in terms of a complex web of knowledge of dynamic geometry, while the students develop their own emergent notions of 'constructing' from the boundary objects produced by the team. Recommendations for boundary object design are considered.

Keywords: action research, boundary objects, communities of practice, design research, dynamic geometry, ethnography, GeoGebra

Introduction

A basic distinction in project evaluation is that between summative and formative evaluation (Frechtling, 2002). Summative evaluation assesses the final outcomes of a project, while formative evaluation assesses ongoing processes, focusing on how that project is achieving its goals. Evaluations reported in the literature are often summative in nature, and explicit cases of formative evaluation are infrequent. One issue here is that the ongoing nature of formative evaluation, and the iterative generation of interim data, present a less tidy unit of analysis than summative evaluation. However, formative evaluations are useful, for instance in design research, where projects follow iterative design cycles of development, implementation, and assessment. Where a summative evaluation may conclude that one intervention has better outcomes than another, a formative evaluation may suggest how to adjust the intervention to be more effective. This paper introduces a formative evaluation of work with the Virtual Math Teams (VMT) Project as it adopts the GeoGebra dynamicmathematics application. One aim of the evaluation is to evaluate the ongoing ways in which the VMT project team is codifying its knowledge of dynamic geometry into the project's online tools and documentation, and how well these tools and documents support students to engage in dynamic geometry. This contributes to the ongoing incremental improvement of the project's artifacts, and is a typical use of formative evaluation (it would be of little use to wait until the project has been completed in order to evaluate these materials). The evaluation approach described in this paper draws on theories of Communities of Practice (Lave & Wenger, 1991; Wenger, 1998) to consider VMT not just as a series of tools, assignments and users, but as an ensemble of people, practices, processes, and other phenomena, which all aim at education in dynamic geometry. The analysis focuses on recent pedagogical artifacts produced by the project, the ways in which these artifacts represent the educational intentions of the project team, and how these artifacts are used by the project's student users. The analysis focuses on the team's understanding of dynamic geometry, the reifications of these understandings in informational artifacts, and the understanding gained by students after interacting with these reifications. An important issue here is the extent to which the design of VMT tools and curricula help students to understand dynamic-geometric construction in the same ways as the project team.

The VMT Project with GeoGebra

VMT is a CSCL project spanning over a decade (Stahl, 2013). The project's technological, pedagogical and analytic components provide an integrated online platform for middle- and high-school students to engage in online mathematical discourse as they explore dynamic geometry. Geometrical construction and explanation are emphasized. In classical geometry, these practices involve the use of a straight edge and a compass. In VMT, these concrete affordances are 'translated' (Stahl, 2013a) into a virtual environment and dynamic screen tools. VMT incorporated GeoGebra for the past several years. The system now includes an online environment with a chat window, a virtual whiteboard, and a range of interactive dynamic-geometry tools, which students use to learn about dynamic geometric construction (Stahl, 2011). The project follows a design-based research

approach, with iterative cycles of user-centered design, implementation and evaluation. The dynamic-geometry tools in VMT have been developed over a number of years by a team of pedagogists, learning scientists, coders, discourse analysts, social scientists, HCI experts, evaluators, and others. Key components of the design process are the team's weekly meetings, in which members discuss topics such as the student chat logs, curriculum design, technological issues, and paper writing. Outputs from the meetings include revised assignments, analyses of project data, drafts of papers, and technical bug reports and fixes. These and other outputs feed into the iterative development of the educational artifacts that mediate the project to its users: the online tools, the tool documentation, the curricula, specific assignments, and so on. It is a form of mutual bootstrapping, with implementations of the tools and curricula generating data for the research team, the analysis of which supports improvements in the tools and curricula, which in turn leads to the generation of new data for analysis. The project team's hope is that by following a design-research process, the educational artifacts they produce will be more useful than a 'one-shot' design approach.

Communities of Practice

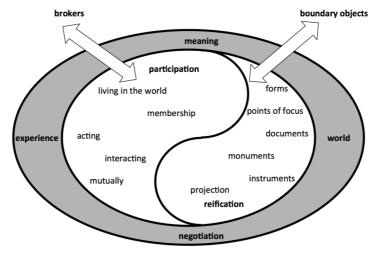


Figure 1. Participation and reification in Communities of Practice. (c.f. Wenger, 1998, Figs 1.1 and 4.1.)

Communities of practice are often glossed somewhat simply as 'groups of people working together on a common task.' The concept has however considerable theoretical depth, including attempting to account for how knowledge is constituted and shared within and between groups. Lave and Wenger (1991) draw on theories of practice by Giddens (1979), Bourdieu (1977), and others, to theorize how newcomers become members of a CoP and gain knowledge of its practices not just by learning what a community knows, but what community members do. This includes knowing what to talk about in that community, and also how to talk and to support community discourse and memory. Experienced community members guide less experienced members through the community's practices, a process known as legitimate peripheral participation, "an engagement in social practice that entails learning as an integral constituent." Wenger (1998) further elaborates membership in a CoP in terms of a duality of participation and reification (Figure 1). Participation involves "the social experience of living in the world in terms of membership in social communities and active involvement in social enterprises," while reification includes a range of activities (making, designing, representing, naming, encoding, and describing, as well as perceiving, interpreting, using, reusing, decoding and recasting") which generate traces of that membership. The processes are distinct yet mutually constitutive: "[Reification] always rests on participation: what is said, represented, or otherwise brought into focus always assumes a history of participation as a context for its interpretation. In turn, participation always organizes itself around reification because it always involves artifacts, words and concepts that allow it to proceed" [pages].

Given that meaning is constituted internally in CoPs in terms of the participation-reification duality, what might individuals external to a CoP make of the reifications of that CoP? Here, says Wenger, boundary objects play an important role. According to Star and Griesemer (1989), boundary objects are:

objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites ... They may be abstract or concrete. They have different meanings in different social worlds but

their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds.

While CoPs regularly appear in the CSCL literature, boundary objects appear less frequently. The rest of this paper therefore focuses on VMT as a CoP and its use of boundary objects.

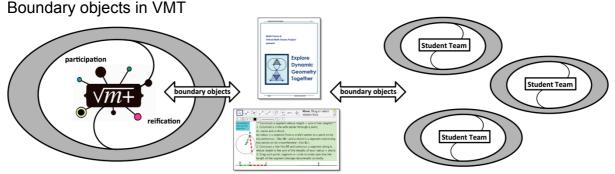


Figure 2. Boundary objects in the VMT project

From the point of view of CoP theory, participation in the VMT project team is built partly on community practices that support project members' knowledge of math, dynamic geometry, the project tools, and the team's educational and pedagogical philosophy. Reification in VMT takes this knowledge and produces artifacts such as the tool interfaces and documentation that represent this knowledge to users. Ongoing cycles of participation and reification have led to the creation of formalized webs of meaning that in turn support the team's practices and identity. This process has been going on for a number of years, with the team's knowledge of dynamic geometry reified in the form of a range of informational artifacts. Many of these artifacts are internal to the project, such as document drafts, meeting agendas and minutes, email, and so on. Other artifacts – boundary objects – have been designed to communicate the project team's understandings of dynamic geometry to wider audiences. Distillations of the team's thinking, these boundary objects are tailored for particular audiences, and include documents such as conference papers, journal articles, funding proposals, and reports. The boundary objects that we are interested in here are designed for students, and consist of sociotechnical ensembles of tools, interfaces, instructions, curricula, and other artifacts. As explicit reifications of the team's knowledge, they are designed to lead students, through a series of activities and exercises, to an understanding of dynamic geometry.

Figure 2 shows, on the left, the CoP of the project team; on the right, a series of small and emerging CoPs that represent various student teams; and in the middle, the boundary objects created by the project team and intended to serve as sense-making artifacts for the students. An important evaluation question here is: Do these boundary objects – which make sense to the team – also make sense to the students and support them to learn about dynamic geometry? To address this question, the students' discourse and actions in VMT are analyzed, using as a starting point Laborde's (2004) distinction between spatio-graphical and theoretical reasoning. According to Laborde, when students construct and use geometrical figures, they can understand these figures at 'face value,' in terms of what they see, and also in terms of wider theoretical reasoning. In learning, students oscillate between these two modes of reasoning, with theoretical hypotheses explored partly through the construction of diagrams, leading to new hypotheses being formed, and an increase in their overall understanding. From this perspective, when examining the VMT student logs, do we see students working their way through the assignments based on 'surface' comprehension of the visual forms that they see on their screens, or do they build theoretical arguments and reasoning to account for the underlying dynamic geometrical forms? The analysis that follows evaluates this question by examining the ways in which the project team and the students use the word 'construction' and its synonyms. Analyzing the use of 'construction' is useful, as such usage can be a marker of both spatio-graphical and theoretical reasoning, depending on the context in which it is used (c.f. Wittgenstein, 2001).

Methodological approach

As noted in the introduction, formative evaluation focuses on descriptions of ongoing dynamic processes, rather than static one-off measurements of project outcomes. It calls for different methods than may traditionally be used in summative evaluation. The research in this paper follows an ethnographic action-research approach (Tacchi, Slater, & Hearn, 2003), combining ethnographic methods with ongoing analyses of and contributions to

the field site. The aim is to develop iterative improvements in theoretical and practical understanding, useful for both the ethnographer and the research subjects. It is a method suitable for complex field sites exhibiting organizational and technological development, such as VMT (Baskerville & Pries-Heje, 1999).

In this analysis, it is assumed that the VMT team produces reifications both for internal use and also for communicating with external stakeholders. The focus here is on boundary objects produced for students, and the students' responses to these boundary objects. The data examined were as follows. First, curricula and manuals related to the VMT tools were analyzed, including introductory assignments, and overall reviews of the project work (Stahl 2012, 2013b, 2014a, and 2014b). Second, the VMT interface, and instructions and assignments were analyzed (screenshots of many of these are included in the documents just cited). Third, the chat of a student group in the VMT Fall Fest 2013 was analyzed (see http://gerrystahl.net/vmt/icls2014/Topic3.xlsx; http://gerrystahl.net/vmt/icls2014/). The analysis followed a general grounded-discourse-analysis approach, in which 'construction' had previously been identified as a main category, and axial codes related to 'construction' were identified. The analysis was carried out using NVIVO coding software.

Results

As might be expected, the curricula, manuals, and the VMT interface, evidenced richer uses of 'construction' than the discourse of the student teams. At the same time, the students used what knowledge they had acquired from the reifications to engage, at times, in creative hypothesis generation. For reasons of space, the analysis in this section is abbreviated.

Curricula and manuals

Across the four documents, 'construction,' as well as 'constructing,' 'constructed,' and a range of synonyms, were used in a wide variety of practical and technical senses. Approximately 180 examples were identified. A common sense usage that emerged from the coding was that of an activity that can be carried out by users:

GeoGebra lets you construct dynamic-mathematics figures

A related usage was that of a thing that was being made or had been made in GeoGebra by students or tutors:

Take turns being in control of the construction. Say what you are doing in the chat.

Use the chat to let people know when you want to 'take control' of the GeoGebra **construction**. Use the chat to tell people what you notice and what you are wondering about the **construction**.

Sliding the history slider shows you previous versions of **constructions** in the GeoGebra tab, so you can review how your group did its work.

Construction was seen as an activity carried out with tools. For instance, the VMT tool has a 'construction area' (i.e. the whiteboard area and associated tool buttons):

Here is how to use these tool buttons. Try each one out in the **construction** area of your own GeoGebra tab. First click on the button for the tool in the tool bar, then click in the **construction** area to use the tool.

Different uses of 'construction' were often combined in the same chunk of discourse, for example:

You can even let someone else take control in your tab to help you **construct** something or to explore your construction. After your group **constructs** something in the group GeoGebra tab, you should make sure that you can do it yourself by doing the **construction** in your own tab.

A wide range of synonyms was also used to describe actions involved in construction, for example:

Use the Compass to **draw** a circle whose radius is equal to the distance between two points and whose center is at a third point. First **click** on two points to **define** the length of the radius. Then without releasing the cursor, **drag** the circle to the point where you want its center to be.

A 'construction' was often seen as the goal or outcome of an assignment. This usage included subsidiary actions, such as creating, dragging, moving, and placing, and subsidiary components such as points, lines, segments, rays, and so on. While this whole/subsidiary distinction was often observed, there were also places where these usages overlapped, for instance where students were expected to construct a figure with underlying dependencies. In these cases, a dependency, although part of the overall figure, could be referred to in itself as a construction:

Note: You must **construct** the dependencies among the objects, (lines and circle), not just **draw** something that looks like this.

Can you think of any ways you could use the dependency **created** with the compass tool or circle tool to **construct** other geometric figures or relationships?

Finally, where one task of the assignment was to come up with a component, this could also be referred to as a construction. For instance, a segment – if it was the outcome of an assignment – could be constructed:

Challenge: **Construct** a segment DG along ray DE, whose length is equal to the sum of the length of a radius AB of a circle plus the length of a segment BC connecting two points on the circumference of the circle.

Interface and assignments

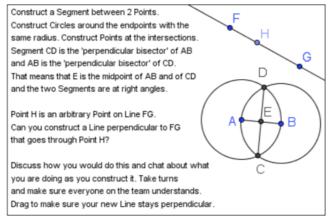


Figure 3. An example of an assignment

The project manuals (previous section) are useful documents, but students may not always read them, and their first encounter with VMT is often through the tool interface. The interface includes several interrelated functional elements, including a whiteboard area in which students can construct dynamic geometry figures with a range of tools, a chat window where they can communicate with other students in their group, and a list of users currently online. Often included in the whiteboard area are informational graphics related to the assignments. The content and format of the graphics varies, but they can be seen as summaries of the description of the assignment in the manual, consisting of a few sentences, step-by-step instructions, and figures (see Figure 3). Graphics are sometimes posted alongside pre-built Geogebra constructions that students can interact with. The assignments summarized in the graphics run from simple tasks that introduce the students to the functions and affordances of VMT, to more complex tasks that test students' understanding of dynamic geometry. As a boundary object, the assignment figure provides a good reflection and synopsis of the associated course materials, although it should be noted that as the description and accompanying figures are succinct summaries, they might require further background understanding in order to be usefully understood (such understanding as is, for instance, provided in the extended explanations in the accompanying manuals). The graphic illustrated in Figure 3 was presented to students in session 3 the Fall Fest of 2013, in which the students had to construct the perpendicular of a line they have previously constructed, and after that to construct a perpendicular bisector through a given point. The word 'construction' is used in several places in this assignment description, and refers both to the construction of various parts of assignment, and the overall goal of the assignment itself (the construction of perpendiculars and bisectors). The assignment also includes elements of dynamic geometry, where the students are instructed to 'drag to make sure your new Line stays perpendicular.'

Student chat logs and constructions

Students use VMT tools to discuss how to approach each assignment, to coordinate their use of the whiteboard and tools, and to discuss what they have learned and discovered in each session. The system is instrumented to capture the traces of student discussion and tool use in GeoGebra is. These logs are regularly analyzed by project members, both individually, and in collective data sessions. The discussion in this section refers to a student session associated with the GeoGebra assignment outlined in the previous section. An excerpt from this log is shown in Figure 4, which shows (left to right) the event number; the time a student started to write a comment; the time the student actually posted the comment; and the comment itself. Because of their login names, this student team, who are middle school students, are referred to by the VMT project as the 'Cereal Team' (sessions by the Cereal team are also reported in Çakir & Stahl, 2015, and Öner & Stahl, 2015).

Start Time	Post Time	cornflakes	cheerios	fruitloops
37:27.9	37:40.4			so now you need to construck points
				at the intersection
38:02.8	38:12.1			no you dont make a line you make a
				line segment
38:31.3	38:35.1			good!!
39:17.4	39:20.4			so continue
38:26.4	39:29.9		i just made the intersecting line and	
			point in the middle	
39:30.8	39:40.0		it made a perpindicular line	
	37:27.9 38:02.8 38:31.3 39:17.4 38:26.4	37:27.9 37:40.4 38:02.8 38:12.1 38:31.3 38:35.1 39:17.4 39:20.4 38:26.4 39:29.9	38:02.8 38:12.1 38:31.3 38:35.1 39:17.4 39:20.4 38:26.4 39:29.9	37:27.9 37:40.4 38:02.8 38:12.1 38:31.3 38:35.1 39:17.4 39:20.4 38:26.4 39:29.9 i just made the intersecting line and point in the middle

Here we can see the three team members, Cornflakes, Cheerios, and Fruitloops. An interesting feature of this session is that while the students often referred to using the tools, they used the term 'construction' relatively infrequently: they used 'make' fourteen times; 'put,' 'move' and other related terms seven times; and 'construct' only twice. For example:

- (17) fruitloops: how do i make the line segment?
- (29) fruitloops: no you dont make a line you make a line segment
- (30) cheerios: *i just made the intersecting line and point in the middle*
- (50) cheerios: *turn line fhg so its easier make it horizontal*
- (57) cornflakes: so after construting the line we put the circle on top
- (63) cornflakes: *put* point m on tp of h
- (85) fruitloops: you make the points go through qr and then you move h ontop of the line

Where construction is part of the students' chat, it seems to be in terms of quoting from the assignment. For instance:

- (28) fruitloops: so now you need to construck points at the intersection (Assignment: Construct Points at the intersections)
- (53) cornflakes: now construct the line (Assignment: Can you construct a Line perpendicular to FG that goes through Point H?)

Line	Start Time	Post Time	cornflakes	cheerios	fruitloops
89	14:10.8	14:29.8			but how do we know for sure that
					the line is perpinmdicular
90	14:37.1	14:39.6		im not sure	
91	14:36.9	14:42.1	there 90 degree angles		
92	14:41.0	14:45.4		do u cornflakes	
93	14:46.1	14:59.4			but you cant really prove that by
					looking at it
94	14:55.4	15:06.8	they intersect throught the points		
			that go through the circle		
95	15:02.1	15:17.7			it has to do with the perpendicular
					bisector
96	15:15.2	15:19.8	they"bisect" it		
97	15:20.0	15:31.2			and the circles
98	15:34.9	15:37.2		oh i see	

Figure 5. "You can't really prove that by looking at it."

One question that could be asked of the students' actions here, following Laborde's model of spatiographical and theoretical thinking, is: Are they generally making, moving, putting, etc., or are they 'constructing' in the dynamic-geometrical sense intended by the term? The discourse of the students describes various acts of manipulation, but there is little explicitly technical reference to any higher order dynamicgeometry principles that could be informing the construction. At the same time, however, the students also engage in some incipient attempts at proof, even if they lack the technical language to describe this in formal terms. This occurs towards the end of their session, where Fruitloops makes some suggestions for summing up the knowledge gained from the assignment (Figure 5). Here, Fruitloops seems to be working towards a distinction between what the students see, what they know, and what they should be able to prove, noting that "you can't really prove that [the line is perpendicular] by looking at it," but rather that the students should aim towards an understanding guided by deeper underlying geometrical thinking.

Discussion

One finding from the analysis is that the VMT project team used 'construction' and related terms in complex ways, while the students used the same terms imprecisely. On one level this should not be surprising. At this stage in their learning of dynamic geometry, the students do not necessarily have at their disposal the range of language and concepts that would enable them to make the rich connections between dynamic-geometry concepts and practices that the project team does. Further, the students seemed to respond literally to the assignment prompts, with the inference that they are demonstrating spatio-graphical responses; that is, they are talking about constructing without having full knowledge of what this might mean in dynamic geometry.

From the point of view of the evaluation framework proposed in this paper, one counter-argument is that the students did in fact develop an understanding of dynamic geometry, but that they did not (yet) possess a sophisticated enough vocabulary to express this in the same terms as the project team. Towards the end of the session described in this paper, and in response to the assignment instruction "Point H is an arbitrary Point on Line FG. Can you construct a Line perpendicular to FG that goes through H?", they test hunches by moving the construction around to see if it aligned. They appear to be working towards a preliminary hypothesis regarding dynamic geometrical proof, even if they do not formally test this, or use the same terminology that a member of the VMT might have used. While from one perspective, this may be seen as spatio-graphical behavior, and lining up different figures with no regard for why they align, at the same time, these actions can also be seen as nascent forms of hypothesis testing based on early understandings of the possibilities for proof in dynamicgeometry environments. This has been suggested in other analyses of the Cereal Team. Çakir and Stahl (2015) studied another VMT session in which the team was instructed to drag previously constructed quadrilaterals, in order to make inferences regarding the underlying dependencies and constructions of these quadrilaterals. They note: "through an interactive process of calibrating and recalibrating their indexical references (Zemel & Koschmann, 2013) to the evolving visual configurations witnessed during different dragging performances, the team members were able to collectively notice several dependencies among constituent elements, describe them in colloquial and semi-formal terms, and produce conjectures for the underlying causes of those dependencies." Similarly, Öner and Stahl (2015), who have analyzed the same session described in this paper, but using Sfard's commognitive framework, suggest that by the end of the session the students are engaged in working towards a preliminary discussion of proof, even if this is not framed in rigorous terms.

From the perspective of Laborde, the Cereal Team iterated rapidly between spatio-graphical responses and theoretical reasoning. This rapid iteration and reasoning was supported by the dynamic nature of the VMT tools and the ability to drag, as well as by the collaborative affordances of the interface, such as the ability to watch other students manipulating constructions in real time, and the chat window for discussion of these manipulations. This iteration was productive; while (as the students observed) the perpendicular bisector figure may look the same from either a spatio-graphical or theoretical perspective, as they interacted with it over the course of the session, the students started to specify differences between these perspectives. They began to posit proto-rules for evaluating whatever it is that they have been instructed to notice in the assignment (constructing a perpendicular bisector), and move from spatio-graphical reasoning and towards theoretical reasoning. Thus, while their discourse consciously reflects at least partly the steps presented in the assignment images and texts – and they recognize that following these steps correctly should result in achieving the assignment goal – they are also aware that the assignment calls on them to provide theoretical accounts beyond those same steps. They recognize that their dynamic constructions can be seen both as spatio-graphical assemblages of components (points, lines, circles), and also as objects that can be explained in terms of more abstract underlying dynamicgeometrical principles. At this stage, however, this reasoning is emergent, not least because of the lack of practice with and reflection upon dynamic geometry, at least beyond the immediate goals of the assignment.

Overall, the VMT tools and documentation functioned well as boundary objects that reified and externalized the project team's knowledge for students. This is not surprising, given the design research approach that the project team uses, which produces regular ongoing revisions to these artifacts. At the same time, the observations, framed within CoP theory, regarding the differences in meaning of 'construction' in both the vocabularies and practices of the project team and the students, suggest further topics for investigation in this process. What are the ontological grounds that the team and the students bring to their understanding of geometry and dynamic geometry? Do the students understand their actions in terms of classical geometry, in which they have yet to be formally trained, or in terms of a translation of dynamic geometry, or in terms of something else again? Further, how do they interpret the affordances of the VMT tools? Do they assume that objects move, unless otherwise specified, and if so, what sort of understanding of dynamic geometry then emerges? These questions lead to a consideration of how VMT can be developed further to support students in theory building and proof. One strategy suggested by the evaluation is to continue to refine the boundary objects produced by the team (in the form, for instance, of assignment images and texts), and to gain further traction

with the students' understanding of what is meant by 'construction.' A second strategy is to understand further the contribution the connections between the collaborative nature of the tools, and the rapid iterations between spatio-graphical and theoretical thinking displayed by the students. (Note: this section benefited from discussion at the 2014 ICLS workshop *Interaction Analysis of Student Teams Enacting the Practices of Collaborative Dynamic Geometry*; http://gerrystahl.net/vmt/icls2014/.)

Conclusion

A formative evaluation of the VMT project, based on Communities of Practice and boundary objects, identified various uses of 'constructing' by project members and students. For the VMT team, the idea of constructing was constituted within a web of dynamic geometry knowledge, and reified in boundary objects such as instructional manuals, assignments, and interfaces. The students drew on these boundary objects, developing notions of 'constructing' which were more emergent. The evaluation recommendations are that the project's boundary objects should continue to be refined, and also that further understanding be gained of what team members and students understand by 'constructing' and related terms. Overall, the CoP approach usefully pulled back the evaluation lens from the tools, and brought into view the project as a whole, covering not just technology use, but organizational levels of design and implementation. The evaluation design allowed insights to be fed back to the project team on an iterative basis, complementing the design research approach of the team.

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Comparing the Benefits of a Tangible User Interface and Contrasting Cases as a Preparation for Future Learning

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Abstract: In this paper we describe an experiment that compared the use of a Tangible User Interface (TUIs) in a constructivist fashion with a traditional learning activity. We carried out an experiment (N=40) with a 2x2 design: the first factor compared traditional instruction ("Tell & Practice") with a constructivist activity (using the Preparation for Future learning framework; PFL). The second factor contrasted state-of-the-art PFL learning activity (i.e., students studying Contrasting Cases) with an interactive tabletop featuring digitally-enhanced manipulatives. In agreement with prior work, we found that students who followed the PFL activity achieved significantly higher learning gains compared to their peers who followed a traditional "Tell & Practice" instruction (large effect size). A similar effect was found in favor of the interactive tabletop compared to the Contrasting Cases (small to moderate effect size). We discuss implications for designing constructivist activities using new computer interfaces.

Introduction

Over the past decades, educational researchers have been advocating constructivist activities to foster meaningful and deeper learning in STEM. This movement was an answer to the behaviorist movement that has been prevalent in educational circles for decades (cf. "programmed instruction" Skinner, 1986), which promoted repetitive exercises to reinforce students' proficiency at following particular procedures, such as applying a particular formula or algorithm to solve a mathematical problem. At least among researchers, over the last decades, there was widespread acceptance of constructivist theories. Constructivism "surfed" on a wave of optimism for many years before educators and researchers realized how difficult it was to design effective discovery learning activities. More recently, some scholars directly attacked this theoretical framework, calling it a failure (Kirschner, Sweller & Clark, 2006). The goal of this paper is to present a case of a successful application of constructivist theories and an analysis of the mechanisms that led students to achieve higher learning gains over traditional instruction. Additionally, we provide evidences that new technologies, such as Tangible User Interfaces (TUIs) have the potential to efficiently support constructivist activities.

Theoretical framework

The general theoretical framework of this paper is the idea that people learn best by using their prior knowledge to make sense of a new learning material (Piaget, 1928); that is, students actively construct knowledge (as opposed to just receiving and accumulating it). In particular, it has also been shown that building artifacts (digital or physical), and going through a process of debugging mental models by externalizing them using different media, are especially powerful (Papert, 1980). This is a major contrast with the traditional "Tell & Practice" instruction (T&P) used in most classrooms, where students are first exposed to the "truth" and then asked to practice their understanding of a particular concept on a series of exercises. Even though this constructivist view of the human mind is generally accepted among the scientific community and is seen as being beneficial to students' learning, there are two main limitations when implementing this approach.

First, students need to have some pre-existing knowledge that they can use to make sense of new concepts; this approach falls short if students don't have any prior experiences in the domain taught or if they don't have the opportunity to build some foundations prior to a lecture. It is likely that students in this situation will resolve themselves to take plenty of notes and memorize as much of the teacher's lesson as possible with the hope that they will understand the content later. This scenario favors rote memorization and hinders transfer (Bransford & Schwartz, 1999). One framework that attempts to mitigate this problem is the Preparing for Future Learning framework (PFL; Schwartz & Bransford, 1998). The idea is to provide students with an open-ended activity prior to the lecture to allow them to construct some intuition about the concepts taught. Schwartz and Bransford argue that Contrasting Cases (CC) are ideal candidates for this task. CC allow students to separate surface and deep features of a problem and provides them with an opportunity for generating self-explanations (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). This framework motivated the first comparison of our study between a PFL-style constructivist activity and a more standard T&P instruction.

The second limitation is that efficient discovery learning activities are notoriously difficult to design (De Jong & Van Joolingen, 1998). It takes serious engineering and designing efforts to create an activity that

engages and motivates learners, target specific learning goals, has affordances for conceptual reflection, works with both high-achieving students and less proficient ones, and allow for productive failure (Kapur, 2008). Contrasting Cases, for instance, are an especially difficult case. Many believed that computer simulations and programming environments would bring a solution to this problem, by providing engaging virtual environments where students could explore rich micro-worlds, and experiment with scientific and mathematic phenomena in a hands-on fashion (Papert, 1980). De Jong and Van Joolingen (1998) conducted a review of the various empirical studies using computer simulations as discovery-learning tools and found some mixed (but mostly positive) effects on students' learning. We build on this prior work and extend this idea to new interfaces appropriate for hands-on learning: Tangible Users Interfaces (TUIs). TUIs are computer systems that replace the traditional mouse and keyboard with physical objects, detect their states (such as their location) and provide a feedback loop to replace the screen with an augmented reality system (for instance by using a projector and displaying additional information directly on the objects). TUIs have specific affordances for constructivist learning, by supporting students' exploration of a complex domain (Schneider, Jermann, Zufferey, & Dillenbourg, 2011), students' engagement and enjoyment (Shaer & al., 2011), small-group collaboration (Schneider & al., 2012) and hands-on activities in co-located settings (Dillenbourg & Evans, 2011).

Our goal is to address those two limitations. First, we want to replicate previous results (Schneider, Wallace, Blikstein & Pea, 2013) showing that providing students with an opportunity to build prior knowledge with a TUI before following a more standard type of instruction is beneficial to learning (compared to a traditional "tell-and-practice" approach, where students are first taught some concepts and then practice their understanding of those concepts on a TUI). Secondly, we want to see how TUIs compare to contrasting cases in terms of preparing students for future learning: in other words, is it worth spending time and energy building interactive hands-on activities? Do they provide any benefits compared to traditional "pen and paper" activities?

General description of the experiment

We designed the following experiment to investigate those two lines of research: in the control group, half of the participants first read an abridged version of a textbook chapter on the human visual system and then completed another activity where they had to apply their new knowledge ("T&P" condition). In the treatment group, the other half of the participants first discovered those concepts in a hands-on activity and then learned about them in a more traditional way, i.e., by reading an abridged textbook chapter ("Invent" condition). Based on the PFL framework, our main hypothesis is that the treatment group should achieve higher learning gains compared to the control group. Additionally, we crossed another factor in our experimental design: the hands-on activity was either a set of Contrasting Cases (CC) or a Tangible User Interface (TUI). We did not have a strong hypothesis regarding this comparison, but expected the TUI group to slightly outperform the CC group on the final learning test; as mentioned above, previous work suggests that TUIs facilitate exploration, increase engagement and support collaborative problem-solving in small groups. Participants were counter-balanced across conditions. We designed measures to look at three potential predictors for learning; engagement (using a questionnaire with validated psychometric properties), curiosity (by having students list all the questions they would like to see answered after the first activity), and quality of their mental models (by asking students to draw a model summarizing their understanding of the topic taught after the first activity). Our goal was to see if students would differ on those measures between our different conditions.

Concerning those measures (engagement, curiosity, quality of their mental models), our hypotheses are as follows: first, the main difference between the "invent" and "T&P" groups should be about the quality of students' mental model and their curiosity. Since the PFL framework is about helping students construct some prior knowledge, we believe that the PFL activity should help them build a mini-theory of how the human visual system works; this difference should be reflected in their drawings after the first activity. In this process, students should be more likely to ask themselves questions and develop their curiosity about the topic taught. This should then help them make sense of a standard instruction (reading a text about the visual system). On the other hand, we expect students in the control group ("T&P") to focus on memorizing the content of the text and spending their time recalling this information when completing the second activity (i.e., using the TUI or working on the CC). Secondly, we expect the main difference between the TUI and CC groups to be about their levels of engagement. Since TUIs have been shown to promote exploration and hands-on learning (Schneider, Jermann, Zufferey, & Dillenbourg, 2011), we believe that the physicality of the system should invite students to be less intimidated by the complexity of the domain taught and explore the problem space to a greater extent. Those two hypotheses motivated the use of measures described below (i.e., middle test measuring the quality of the students' mental model and their curiosity, and a questionnaire measuring their engagement). Finally, we did not have any hypothesis regarding an interaction effect between our two factors (i.e., we don't have any reason to believe that CC or the TUI should have a differentiated effect on students in the PFL or T&P conditions.)

Methods

Participants

40 students from a community college participated in this study (13 males, 27 females; mean age = 21.28, SD = 4.08). Students signed up for the study as part of a psychology class. The only prerequisite for participating was to have no prior knowledge on the topic taught (neuroscience and the visual system). Students were randomly assigned to each experimental condition.

Material

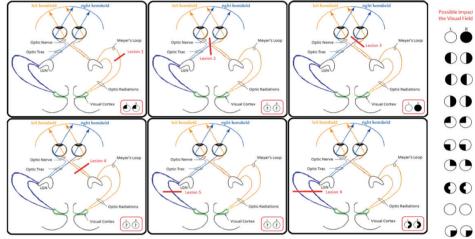
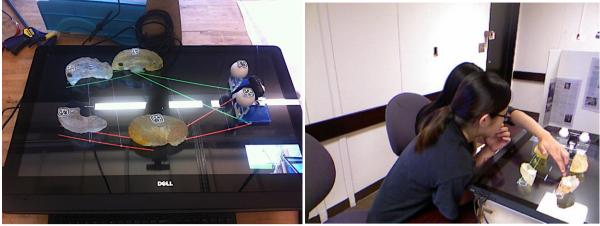


Figure 1: The set of contrasting cases used in the study. Answers are given for diagram 1, 3 and 6. Potential answers for the remaining cases are shown on the right column.

This study included three different activities (Fig. 3). In the "invent" condition, students first explored the domain taught with either a TUI or a set of contrasting cases. The TUI is described below (Fig. 2); the CC (Fig. 1) included 6 diagrams of the human brain, each one featuring a different lesion. Half of the CC showed the correct answer to students (i.e., case 1, 3 and 6). The right column showed potential answers for the remaining cases. After finishing the first activity, students answered the following two questions: 1) "By the end of this first activity, what are the questions that you would like to see answered about the way the human brain processes visual information?" and 2) "Please draw a simple model that summarizes your understanding of the way the human brain processes visual information." During the second activity, students read an abridged version of a textbook chapter explaining how visual information is processed in the human brain (available at: http://goo.gl/47RIwv). Finally, they took a post-test that included questions on the terminology used (students had to correctly label different brain regions and neural pathways), on the effect of various lesions on the visual field (given a particular lesion, students had to draw its effect on a person's visual field), and on more general scenarios involving human vision (transfer questions). Finally, we asked them to fill the engagement questionnaire designed by O'Brien, Toms, Kelloway, and Kelley (2008). This questionnaire was developed for researchers in HCI (Human-Computer Interaction) and measures six dimensions of an activity that relates to users' engagement (33 items on a Likert scale): focused attention (9 items; e.g., "I forgot about my immediate surroundings while doing X"), perceived usability (8 items, e.g., "I felt frustrated / discouraged / annoyed while doing X"), aesthetics (5 items, e.g., "X was aesthetically appealing), endurability (5 items, e.g., "I consider my experience with X a success"), novelty (3 items, e.g., "I continued to do X out of curiosity") and involvement (3 items, e.g., "I was really drawn into X"). In the T&P condition, the order of the learning phases was reversed (students first read the text and then completed the TUI or CC activity).

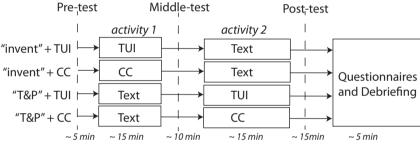
The TUI used in this study is an improved version of a system previously developed in our lab (Schneider, Wallace, Blikstein & Pea, 2013), called BrainExplorer. BrainExplorer (Fig. 2) allows students to physically manipulate a small-scale replica of a brain while an interactive tabletop displays visual pathways between brain regions. Users can then cut those pathways to create lesions and observe their effect on the visual field of a subject. Two eyes (with a webcam) captured the field of view of this brain and shows occlusions on the corresponding visual field.

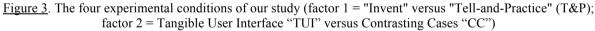


<u>Figure 2</u>. The TUI used in this experiment (BrainExplorer). The system on the left shows the tangibles that students can manipulate with the field of view of this brain (bottom right corner of the table). The image on the right shows two students interacting with the system during our study.

Design

We used a 2x2 between-subjects experimental design (Fig. 3). The first factor had two different hands-on conditions: the tangible interface and contrasting cases. The second factor sequenced the two learning activities in different ways: either with the hands-on activity first ("invent" \rightarrow "read") or second ("T&P").





Procedure

The experimenter ran students in groups of two in a private room. Upon their arrival, the experimenter welcomed them and told them that they would complete two small learning activities in groups. They were also told that the topic taught was about neuroscience and the human visual system. After filling a pre-test, students completed two learning activities: In the "invent" condition, they first did the hands-on activity (i.e., TUI or CC) and then read a text about the visual system. In the "T&P" condition, they first read the text and then practiced their understanding of the topic on the hands-on activity. A second factor was crossed with those two conditions: students either worked with the CC or TUI for the hands-on activity. Thus, referring to Figure 3, students in the "invent" + CC condition followed the same procedure except that they used the TUI instead of the CC. Students in the T&P + CC first read a text and then applied the concepts they just learned on a set of CC. Students in the T&P + TUI followed the same procedure except that they reinforced their understanding of the topic was 15 minutes long.

Between the two activities, the experimenter gave students two questions to answer individually (10 minutes): first, they had to list the questions that they wanted to see answered about the human visual system after the first activity (i.e., a measure of curiosity); second, they had to draw a model summarizing their understanding of the concepts taught (see the "material" section for more information)., students individually completed a post-test (15 minutes) and were thanked for their participation.

Coding

The pre-tests and post-tests were coded in a binary fashion (1 point for a correct answer, 0 point for an incorrect answer). For the middle test, we counted the number of questions students had and applied a simple rating scheme to their models: 1 = no useful information shown; 2 = some useful information, mostly about the terminology used (no or little conceptual understanding of the effect of lesions on the visual field); 3 = significant signs of understanding of the way visual information is processed by the human brain. Figure 4 provides an example for each category. Only one researcher coded the tests and the drawings, because the coding schemes were simple and straightforward to apply.

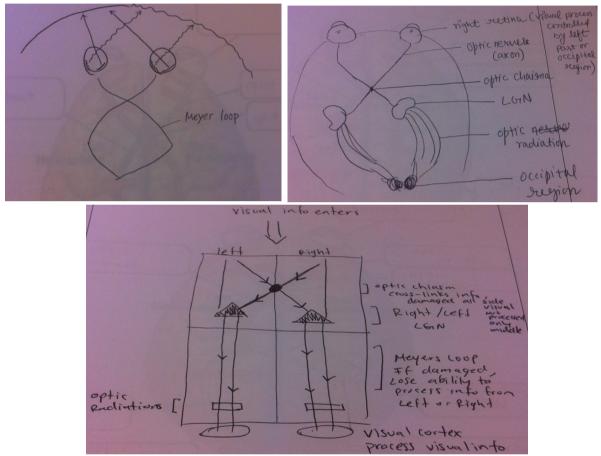


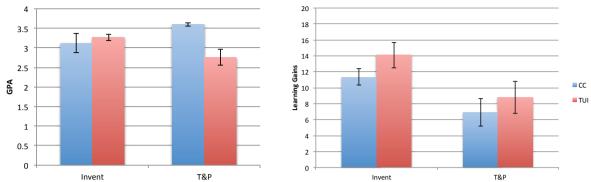
Figure 4. Three examples of models drawn by our participants. The model on the top left received 1 point (= no or little useful information); the one on the top right received 2 points (= some useful information, mostly about the terminology); and the one on the bottom received 3 points (= clear signs of conceptual understanding).

Results

Since our samples are not independent (i.e., members of a dyad influenced each other) and since the intraclass correlation for the learning test is significant (p < 0.001; Kenny, Kashy & Cook, 2006), it is advised to conduct analyses at the dyad level. Since this reduced our statistical power, we will also report results where p < 0.1 with a moderate effect size. We also checked students' Grade Point Average (GPA), since populations in community colleges are known to be heterogeneous. Because there was an interaction effect: F(1,16) = 4.46, p = 0.049 (Fig. 5, left side) between the two levels of our factors, we used GPA as a covariate for the following analyses.

Learning gains

The results supported our two main hypotheses. Since participants did not score any points on the pre-test, we only considered their results on the post-test. Scores are shown on Figure 5 (right side). An ANCOVA revealed that students in the "Invent" condition outperformed students in the "T&P" condition: F(1,16) = 15.45, p < .001, Cohen's d = 1.41 (for the "invent" group, M = 12.95, SD = 3.15; for the "T&P" group, M = 7.85, SD = 4.06). Additionally, students using the TUI outperformed students in the CC group: F(1,16) = 5.32, p = .036, Cohen's



d = 0.48 (CC: M = 9.35, SD = 3.90; TUI: M = 11.45, SD = 4.74). All distributions were checked for normality and homogeneity of variance.

<u>Figure 5</u>. Left: distributions of students' GPA. Right: Results on the learning test (Standard Errors shown). CC stands for Contrasting Cases, TUI for Tangible User Interface and T&P for "Tell-and-Practice".

Curiosity and mental models

Additionally, we looked at the effect of our two factors on the results of the middle-test (i.e., the number of questions students would like to see answered about this topic – a crude measure of curiosity – and the quality of the model they drew). For the first factor, we found that students in the "Invent" group created significantly higher quality models compared to the students in the "T&P" group: F(1,16) = 7.38, p = .016, Cohen's d = 1.32 (for the "invent" group, M = 2.00, SD = 0.56; for the "T&P" group, M = 1.35, SD = 0.41). There was no significant difference in terms of the number of questions they asked themselves: F(1,16) = 2.75, p = .118, Cohens'd = 0.81. For the second factor (TUI vs CC), both comparisons were not significant (F < 1). We then correlated those two measures with our main dependent variable. Both measures were significantly associated with higher learning gains: r(20) = .40, p = .043 for the number of questions students asked themselves and r(20) = .55, p = .007 for the quality of students' model.

Engagement

Finally, we looked at the engagement questionnaire administered at the end of the study (see Table 1). We found that participants in the "Invent" condition were more engaged (aggregate measure of all the items) than the students in the "T&P" group: F(1,16) = 6.1, p = .025, Cohen's d = 1.05. Results were significant on the "endurability" sub-dimension (p < .05) and marginally significant on the "Focus" (p = .096), "involvement (p = .068), novelty (p = .066) and aesthetics (p = .071) sub-dimensions. Similarly, students in the "TUI" group were marginally more engaged compared to the "CC" group: F(1,16) = 3.4, p = .064, Cohen's d = 0.80. They found the TUI to be more usable (p < .05) and rated the endurability and aesthetics' dimensions marginally higher (p = .108 and p = .114, respectively). Across all participants, being engaged was significantly correlated with higher learning gains (p = .015); more specifically, involvement and endurability were the only sub-dimensions significantly correlated with students' learning (p = .011 and p = .03, respectively).

	Focus	Involvement	Novelty	Endurability	Aesthetics	Usability	Engagement
TUI vs CC	<i>F</i> < 1	F < 1	<i>F</i> < 1	F = 2.9	F = 2.8	<i>F</i> = 5.4	F = 3.4
				p = .108	p = .114	p = .033*	p = .064
				d = 0.45	d = 0.73	d = 0.85	d = 0.80
Invent	F = 3.1	F = 3.8	<i>F</i> = 3.9	<i>F</i> = 4.7	F = 3.7	F < 1	<i>F</i> = 6.1
vs T&P	<i>p</i> = .096	p = .068	<i>p</i> = .066	p = .045*	p = .071		p = .025*
	d = 0.45	d = 0.71	d = 0.72	d = 0.77	d = 0.70		<i>d</i> = 1.05
Correlation	<i>r</i> = .33	<i>r</i> = .56	<i>r</i> = .33	<i>r</i> = .49	<i>r</i> = .36	<i>r</i> = .21	<i>r</i> = .53
with learning	<i>p</i> = .152	<i>p</i> = .011*	<i>p</i> = .154	<i>p</i> = .030*	<i>p</i> = .122	<i>p</i> = .380	<i>p</i> = .015*

Table 1: Engagement scores between our experimental groups.

Notes: Row 2 and 3: MANCOVA between the two levels of our two factors on the dimensions of the engagement questionnaire. Row 4 reports correlations with students' learning gains. Degrees of freedom are indicated as above: r(20) for the correlations, and F(1,16) for the F-tests; d is Cohen's d.

Linear regression

We ran a linear regression to find how much variance of the learning gains our main predictors could explain (i.e., number of questions on the middle-test, complexity of students' mental model, endurability, involvement). We found that the quality of students' mental model was the strongest predictor ($\beta = .43$), followed by the endurability variable ($\beta = .30$), students' involvement ($\beta = .22$) and curiosity ($\beta = .12$). Altogether, these four variables explained more than half of the variance of students' learning gains: $R^2 = .58$, F(4,18) = 4.78, p = 0.012 (Table 2).

Variable Name	β	t-test
Endurability ("students' perception of success")	.304	t(15) = 1.35, p = .199
Involvement	.224	t(15) = 0.94, p = .361
Curiosity (Number of Questions Asked)	.119	t(15) = 0.60, p = .555
Quality of Students' Mental Model	.434	t(15) = 2.34, p = .035*

Table 2: Linear regression with students' learning gains as the dependent variable ($R^2 = .58$)

Discussion

The main goal of this paper was to show that technologically enhanced hands-on activities (i.e., TUIs) have the potential to increase students' learning in traditional constructivist activities. We also wanted to replicate previous results showing the benefits of creating prior knowledge before receiving formal instruction. Our results suggest that PFL activities have a large effect on students' learning. When prompted to explore a domain by themselves before reading an abridged textbook chapter, students developed more refined mental models, became more curious, more engaged and perceived themselves as being more successful (compared to the students in the T&P group); additionally, those differences were associated with higher learning gains. The fact that students created better models based solely on their analyses of the contrasting cases or by interacting with the TUI is promising: it shows that providing students in the control group (T&P) with an already complete set of diagrams prevented them from creating their own model; worse, they didn't even internalize the ideal model from the textbook in a proper way. Additionally, our results suggest that using a Tangible Interface as a preparatory activity has a positive effect on students' learning compared to studying CC. Participants learned more when using the interactive system and felt more engaged compared to the CC. Marginally significant effects suggest that students using the TUI felt more successful with the task ("endurability"), which was correlated with higher learning gains. They also found the activity to be more aesthetically appealing and the TUI to be more usable, but those measures were not associated with higher learning gains.

However, those measures do not provide us with the full picture; it is likely that the TUI had a beneficial effect on students' learning beyond their level of engagement. We suggest a few hypotheses to be tested in future work. First, BrainExplorer, and similar TUI-based exploratory systems, provide students with "on-demand" or "just-in-time" information about the visual system. From our qualitative observations, we saw students develop different strategies when using the system. Some were more confortable using a "bottom-up" approach (i.e., they started by analyzing the pathways from the eyes to the LGN, and then from the LGN to the visual cortex); some others followed the same approach, but in reverse; finally some students started by making as many lesions as they could, and then focused on more specific regions. In future work, we plan to compare the variety of strategies used in both conditions (TUI vs. CC) to test this hypothesis. Secondly, it is possible that using a TUI had an indirect effect on students' collaboration, which in turn had a positive effect on learning. For instance, it is conceivable that students found it easier to explore the problem space together (Schneider, Jermann, Zufferey & Dillenbourg, 2011), share information and build hypotheses (Shaer & al., 2011) with the TUI. We plan to code students' quality of collaboration and correlate those measures with learning gains in future work. Finally, It is possible that the results above were caused by a novelty effect; this is the most natural explanation for the significant effect found between TUI and CC, since most students had likely not interacted with a tangible interface in the past. However, the statistical analyses performed on the "novelty" dimension of the engagement questionnaire did not support this explanation. Future work will look more closely at this possible confounding variable.

It is worth mentioning that we do not take those results as evidence that TUIs are better learning activities than CC beyond the scope of this experiment. Both activities can take many forms, and their efficiency is strongly influenced by a variety of design choices. Our findings merely suggest that the TUI introduced in this paper (BrainExplorer) seemed to promote higher learning gains compared to the CC presented above. In summary, more analyses are needed both in collecting qualitative segments suggesting explanation for the

higher learning gains found in the TUI (versus CC) condition, and in analyzing the logs of the system to determine students' strategies when exploring BrainExplorer.

Conclusion

This paper presented a successful application of the "Preparing for Future Learning" framework to education in a complex field of knowledge (neuroscience). Our findings suggest that, under certain circumstances, minimally guided instruction can be beneficial to learning. Our measures suggest that our intervention dramatically influenced the quality of students' mental models, which had a positive effect on their learning gains. This measure, associated with students' curiosity, involvement and perception of being successful at the discovery task, predicted more than half of the variance of their scores on the post-test. This shows the positive effect of using constructivist-inspired preparatory learning activities for learning scientific concepts. Those results, combined with others (e.g., Schwartz & Bransford, 1998; Schwartz & Martin, 2004), confirm that there is still a considerable gap between educational research (that advocates a constructivist view of students' learning) and regular classroom instruction (that still prevalently use a "T&P" framework). The contribution of this paper is to propose a step toward closing this gap. We suggest combining the affordances the new technologies (e.g., TUIs) with existing educational frameworks (e.g., PFL) to provide students with compelling, carefully-crafted hands-on learning experiences that prepare them for future learning.

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Impacts on Student Understanding of Scientific Practices and Crosscutting Themes through an NGSS–Designed Computer-Supported Curriculum and Instruction Project

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Abstract: This paper presents a curriculum intervention intentionally designed to align with *Next Generation Science Standards* in the high-school biology classroom. The project emphasizes learning about complex systems through an agent-based modeling tool called StarLogo Nova. Five curricular units have been developed on the topics of enzymes, ecology, protein synthesis, gene regulation, and sugar transport. In this exploratory study we were interested in understanding the extent to which students demonstrated understanding and skills in NGSS areas as they were designed. Evidence is gleaned from classroom observations and interviews with 50 students selected from the larger population of 352 students who worked with project resources during the 2013-2014 school year. Findings revealed that students demonstrated understanding and skills in all NGSS scientific practices and crosscutting themes particularly in the areas of developing and using models, analyzing and interpreting data, cause and effect, and systems and system models.

Keywords: education, learning outcomes, science education, simulations

Introduction

The release of the *Next Generation Science Standards* (NGSS) in the US has required a shift in understanding and doing science in the classroom. There is a greater focus than ever before on problem-solving, applying knowledge, argumentation, systems thinking, and constructing models, to name a few differences from previous science education standards. This new vision of science education is instantiated in scientific practices and crosscutting themes that permeate domain-specific content and requires new pedagogical approaches, curricula, and resources. As we begin to translate the NGSS into classroom practice, we need to articulate and explore activities that adequately address the standards with fidelity to their original intent (Bybee, 2013; NRC, 2014a; NRC, 2014b). In this paper, we highlight a curriculum and instruction project that was constructed to tightly align with the NGSS. Through the central learning goal of developing complex systems understanding in high school biology, the project team has developed five units in the content areas of enzymes, ecology, protein synthesis, gene regulation, and sugar transport. The project is anchored in activities delivered through computer simulations constructed in *StarLogo Nova*–an agent-based modeling program with a 3D game-like interface. The curriculum includes student packets and teacher guides that support teaching and learning about biological systems through, among other things, modeling, argumentation, mathematical and computational thinking, and collaboration.

We have worked extensively with teachers in professional development (PD) activities and have piloted project resources in classrooms over the last two years. Thus, we are aware that myriad variables can impact the success of a new intervention. For example, Wilson (2013) states that helping teachers acquire this new set of pedagogical tools to teach using the NGSS is a challenging task. Through research on fidelity of implementation of science education interventions, we also know that criteria such as adherence to the intervention's design, and quality of delivery can significantly impact student-learning outcomes (Lee et al., 2009). We have written about our experiences with teachers (Yoon et al., accepted) and implementation variables (Yoon et al., 2013) elsewhere. Here our major goal was to conduct an exploratory study to determine the extent to which students in our project demonstrated knowledge of and skills in the NGSS scientific practices and crosscutting themes. A secondary goal was to identify those practices and themes that were most frequently shown by students thereby locating particular strengths of the project activities and resources. Below

we describe the curriculum and instruction framework that underpins all project activities and provide a sample of the curriculum that highlights its alignment with NGSS standards.

Research on the next generation science standards

Developing curricular materials and pedagogical tools for NGSS is an important next step in implementing these reforms. Currently, two of the primary challenges facing implementation of NGSS are developing curriculum materials and instructional strategies that successfully instantiate them (Bybee, 2013). Despite significant standards reform, "much science and mathematics teaching still emphasizes rote skills and memorization" (NRC, 2014b, p. 136). While there are curricular developments intended to support NGSS learning, they are developed at the state level and different standards are favored or deemphasized depending on local preferences (NRC, 2014a). None adequately address the entire range of new skills outlined in the NGSS (Penuel et al., 2014), though most promising among these are project-based curricula, such as the Project Based Inquiry Science (PBIS) units funded by NSF, that combine scientific knowledge with constructing arguments and using models (Harris et al., 2014; Penuel et al., 2014). Our project activities were designed around a curriculum and instruction (C&I) Framework based on the NGSS that includes the same promising characteristics of PBIS.

Curriculum and instruction framework (C&I)

The C&I framework is divided into four categories that are aligned with NGSS in addition to the literature on needs and best practices for STEM teaching and learning (Figure 1). The first category is *Curricular Relevance*, which focuses on developing 21st century competencies (NRC, 2012), ensuring standards alignment (Desimone, 2009), and collaboration with teachers to promote teacher ownership (Ertmer et al., 2012, Mueller, 2008; Thompson et al., 2013). The second category, *Cognitively-Rich Pedagogies*, involves pedagogies that address situated needs in individual classrooms (Penuel et al., 2011), social construction of knowledge through collaboration and argumentation (Osborne, 2010), and constructionist learning by constructing models (Kafai, 2006). The third category, *Tools for Teaching and Learning*, builds knowledge through computational modeling tools (Epstein, 2008), teacher guides and student packets that provide scaffolds for learning with technology (Quintana et al., 2004), and off-computer participatory simulations to support students' understanding of modeling and complex systems (Colella et al., 2000). The fourth category, *Content Expertise*, builds deeper content understanding in complex systems (Author, 2008), biology (Lewis & Wood-Robinson, 2000), and computational thinking (NRC, 2010).

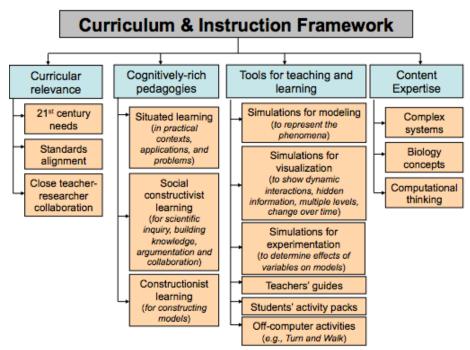


Figure 1. Teaching and learning about complex systems C&I framework

To better understand how the C&I framework informed the construction of the curricular units, we briefly describe an activity in the enzyme unit *Chew on This!* In this activity students are asked to explore the break

down of starch into sugar that begins in your mouth and is completed in the small intestine. The simulation enables students to compare and contrast the conversion of starch to sugar both with and without enzymes. The aim is to help students understand the role of enzymes in digestion. Students conduct various experiments and are asked to plot the results and share their data with others in the class. Students can take as much or as little time as they would like to observe the behavior of starch. Along the way students are asked to pick among several claims and in groups come to consensus on the evidence and reasoning used to support the claim to help them understand various aspects of the science. Figure 2 shows an excerpt from the student activity packet. Here students are asked to observe and consider the random movement of enzymes in the system. Figure 3 shows a snapshot of the simulation with a sample student's graph constructed with data collected while interacting with the simulation, which is a representative task students complete in these units.

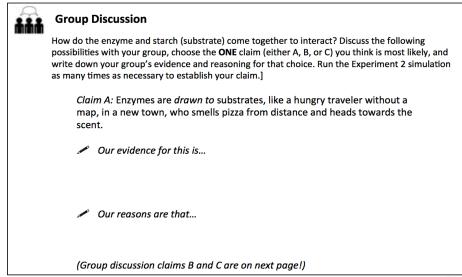


Figure 2 Excerpt from student packet showing directions to use an argumentation process

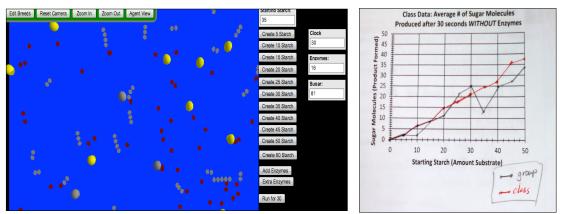


Figure 3. Simulation of Chew on this! and student graph of system variable change over time

Methods

Context and participants

To address our research goals, we conducted observations and interviews with students in 2 participating schools comprised of 5 classrooms in the greater Boston area, during the 2013-2014 school year. In school A, in terms of selected demographic and academic variables, 59% of students were on free or reduced priced lunch, 68% identified as non-white, and 61% scored at or above proficient on the state standardized science exam. In school B, 34% of students were on free or reduced price lunch, 38% identified as non-white, and 70% scored at or above proficient on the state standardized science exam. In school B, 34% of students were on free or reduced price lunch, 38% identified as non-white, and 70% scored at or above proficient on the state standardized science exam. In the subsample of the larger study population, 56 students in groups of two were randomly selected to be video taped interacting with the simulation and activity

packet for the unit *Chew on This!*. We also conducted 3 focus group interviews with 13 randomly selected students to understand in more detail the learning benefits accrued through interaction with project activities.

Data sources and analysis

A total of 14 hours of video footage was captured of students participating in this unit. Video cameras were specifically focused on groups of students while they engaged with the simulation. The second data source came from student focus group interviews, which were conducted at the end of each classroom observation with 3 or 5 students.

NGSS	Subdomain Descriptions	Examples Within BioGraph Context
Primary		
Categories		
Science and Engineering Practices	Developing and using models : using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds	Yeah, I didn't know if they sought out all the time or if they were just moving randomly most of the time. So I tried I think it was like 20 starches and then I added like 10 enzymes. I thought because it was 10 and 20 that it would come out like that, but it didn't. It came out to totally different numbers and that just made me understand how no matter the number, you can always have different outcomes. (ID 5, Focus Group, 11/21/2013)
	Planning and carrying out investigations:	I think since we had the control over how many
	investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.	starches and how many enzymes we wanted to add helped a lot because I think by five intervals and everything like that, but you could change it manually to whatever number you wanted. So I think having the control over it helped a lot because then if we were unclear on something we could Like if a greater number of starches versus a smaller number of enzymes and vice versa, we could see how it interacted and how it changed. (ID 5, Focus Group, 11/21/2013)
Crosscutting	Cause and effect : empirical evidence is required	And then even though this was with starch
Concepts	to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.	specifically, it also taught me how enzymes are really important in the human body and everything like that because without them you wouldn't be able to break down food. And if you couldn't break down food you would have a serious problem and you'd get sick and you would gain weight. So it helped me understand how enzymes really have a big impact on the digestive system and everything like that. (ID 5, Focus Group, 11/21/2013)
	Systems and system models : investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. They can also design systems to do specific tasks.	Couldn't it partially be complex systems because it shows how the enzymes decide what, if they're going in any sort of pattern to find the starch. Whether they're following them or just bumping into them randomly. They're just traveling around. Kind of being like a random complex system. (ID 3, Focus Group, 10/17/2013)

Table 1: NGSS coding framework and examples

The interview protocol was comprised of 5 semi-structured questions that explored students' perceptions of the pedagogy, what they learned in terms of biology and complex systems, and what they thought about the use of computational tools to support their learning. The interviews lasted for 25 minutes on average.

Both data sources were coded according to a framework directly adapted from the NGSS to assess student learning. A categorization manual was constructed using descriptions of the 8 scientific practices and the 7 cross cutting themes (NRC Framework, 2012, p. 30). The videos were coded using the method of Interactional Analysis (IA) which involves collaborative analysis of video and/or audio clips by a group of researchers to examine the details of social interaction (Jordan & Henderson, 1995). The basic goal of IA methodology is to use video and/or audio data to understand what people are doing during their social and discourse interactions and if, how, and what people are learning. The collaborative investigation avoids the preconceived notions of a single researcher. The IA constituted of over 30 hours of collective coding between three project researchers. Transcripts of focus group interviews were coded for the frequency of utterances indicating learning of each specified NGSS category. The first 20% of data was coded independently by four project researches until internal reliability was satisfactory ($\alpha = 0.78$). An individual researcher then coded the remainder of the focus group interviews. A full version of the categorization manual cannot be accommodated in this paper format however Table 1 shows a selection of several scientific practices and crosscutting themes with codes and examples from the student data.

Results

Results from the video data and focus group analysis indicate that students demonstrated understanding and skills in nearly every NGSS category. As expected, some topics were more prominent than others. We discuss salient findings below.

Video data observations

Figure 4 shows the distribution of video observation data. Out of 390 coded utterances, 76 referred to analyzing and interpreting data. The second most frequent Science and Engineering Practice observed in the video data was developing and using models with 70 utterances. From the Cross Cutting Concepts, cause and effect had the greatest number of utterances with 43.

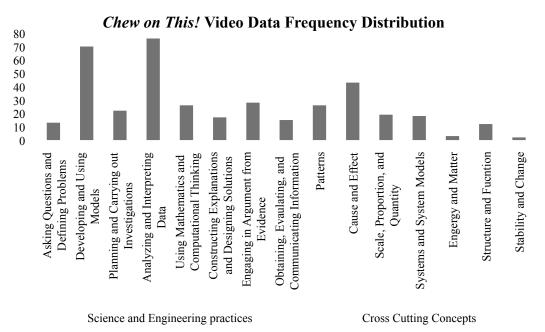


Figure 4. Video observations of Chew on This! frequency distribution of NGSS codes

As evidence of student learning, the following example includes the discourse between a group of students answering a multiple-choice question in the student packet after running several experiments and collecting data on how much sugar formed over time. The question states: "Based on the experiments just run *without* enzymes, the graph of the amount of sugar produced vs. starting amount of starch looks most like?"

Figure 5 below provides an illustration of the four answer choices followed by the corresponding student discourse.

In this example, there is evidence that students were learning a number of NGSS skills. Here the students were analyzing and interpreting their data (numbers of sugar and starch molecules over time) obtained from using the model to determine which graph best represented the rate of change from starch to sugar. Since their data was numerical and the question involved understanding graphical representations, this is also evidence they were using mathematics and computational thinking. Initially S1 described her data (line 1) and others corroborated the results (lines 2-3). They then began analyzing the data to link their numbers to the appropriate graph (line 4). The answer was not immediately apparent and they continued this discussion and analysis of their numbers (lines 5-8). The entire discussion is also evidence that the students were communicating their findings and engaging in argument using their data to support their answer choice.

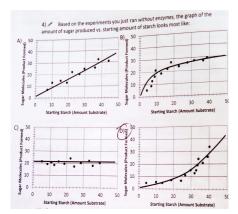


Figure 5. Graphs from student packets

Excerpt from ID 2, Video Data, 11/21/2013, 20:10-20:50

- 1. S1: Mine there was a point where it was increasing and then decreasing and then increasing again.
- 2. S2: Yeah, me too.
- 3. S3: Me too.
- 4. S4: So that's not C, that's D.
- 5. S2: Yeah between 25 and 40 mine went up down up down
- 6. S1: So it's B. Mine was weird because it was like 0, 5, 7, 2, 13, 14
- 7. S2: So I think it would be B because it goes up and then...
- 8. S4: Yeah there's like a point where it kind of slows down.

Focus group interviews

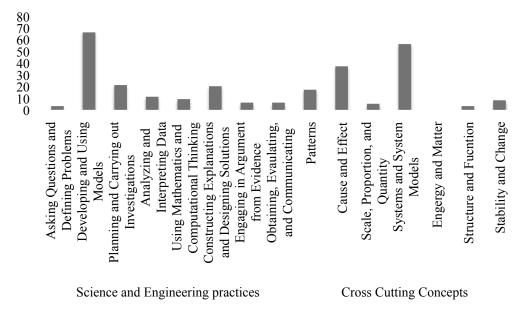
Figure 6 shows the distribution of focus group interview data. Of the 122 coded utterances, in reference to Science and Engineering Practices, 66 were coded as developing and using models. For Cross Cutting Concepts, the greatest frequency of utterances, 56, were coded as having to do with systems and system models. For example, in response to the question *What is the main biology idea represented in the unit?*, one student responded:

We learned how over time starch turns into sugar because we had to click that 5 starch, 10 starch, 15 starch thing and then like each had 30 seconds. And then as many starch comes, and just for the same amount of time, it's different. Different answers come out." (ID 1, Focus Group, 11/22/2013)

In this excerpt, the student recognizes the relationship that sugar and starch develop over time through scaffolded interactions with the model. In understanding cause and effect another student remarked:

We were discussing [the argumentation question] once and I ran [the simulation] like five different times just to see the different answers. (ID 3, Focus Group,10/17/2013).

Here, he and his partner debated how to answer the argumentation question, which required students to provide evidence for their reasoning. In order to be able to provide evidence, the student went back to the simulation and ran it multiple times to find the empirical evidence that they needed to understand the relationships being shown in the simulation. The students interpreted evidence to respond to the question prompt in order to understand cause and effect.



Chew on This! Focus Group Frequency Distribution

Figure 6. Focus group interview frequency of utterances of NGSS codes

Discussion

The recently developed Next Generation Science Standards have expanded the goals of K12 science education to emphasize problem-solving, applying knowledge, argumentation, using computers, systems thinking, constructing models, and making connections across scientific domains. Implementing these standards requires new and appropriate curricula and pedagogical tools-two components critical to success but remain a challenge for researchers and educators. In order to address the need for curricular materials and pedagogical approaches that instantiate the recent NGSS, our project has developed a five-unit biology curriculum using simulations, argumentation, computational thinking, and systems understanding in conjunction with traditional Biology content. In this study, we present findings from one unit of our project on enzymes, to investigate whether students interacting with project materials demonstrate the science and engineering practices, and crosscutting concepts outlined in the NGSS. Based on the results, we have concluded that students can demonstrate knowledge and skills in all but one of the science and engineering practices and cross cutting concepts as is evident in classroom observations of students engaging with the simulation and in their self-reported learning during focus group interviews. To answer the second research goal of identifying those practices and concepts that were most frequently shown by students thereby locating particular strengths of the project activities and resources our findings show that using models, analyzing and interpreting data, understanding cause and effect, and systems understanding were the most prominent. Overall, we have shown evidence of students learning the science and engineering practice and the cross cutting concepts. Students are grappling with data, and using and manipulating models to understand systems.

In the future, an experimental study would validate these findings, since a limitation of the current study is the lack of a control group. As such, we do not know how much of the NGSS is incorporated into student learning outside of our project intervention, so this warrants further exploration. Our findings do provide insight into curriculum development for the NGSS, in that we have shown how science and engineering practices, and crosscutting concepts can be incorporated into curriculum content.

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Examining the Real and Perceived Impacts of a Public Idea Repository on Literacy and Science Inquiry

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Abstract: Public idea repositories can facilitate beneficial interactions among students. They moreover offer contexts for developing inquiry and literacy skills, as they position students as writers, and not just reviewers of science. Access to peers' ideas can diversify students' thinking, but also reinforce existing understanding. We investigate the real and perceived impacts of different prompts for students' use of peers' ideas. 144 middle school students used an online tool to exchange ideas during a science inquiry unit. Students prompted to seek ideas different from their own perceived their peers as having greater impact on their thinking than students prompted to seek ideas that reinforced their own. Although students' revisions after exchanging ideas showed no actual change, students who diversified their ideas later showed significantly greater pre to post test gains. These findings suggest ways that technologies can be designed to best support students in taking advantage of peers as learning resources.

Keywords: public idea repositories, science inquiry, literacy, middle school, collaborative web-based curriculum tools, design experiment

Introduction

A principle in designing collaborative learning is to encourage exposure to others' ideas (Scardamalia, 2002). In comparing and contrasting different points of view, students strengthen their own understanding. Whereas it can be difficult for teachers to coordinate and track face-to-face interactions among their many students, technology can relieve some of this logistic burden, and promote students' exposure to others' ideas in ways that both improve and motivate science learning (e.g., Looki, Chen & Ng, 2009).

Public knowledge repositories, through which students can exchange ideas, offer authentic contexts for developing collaborative inquiry skills. Importantly, participating in the construction of a public knowledge repository positions students as writers, and not just reviewers of science (Scardamalia & Bereiter, 1993). It challenges them to articulate their understanding and as well as to select, evaluate, organize, synthesize, and interpret new ideas in relation to existing ones. This can help develop students' broader information literacy, which includes, among other things, an understanding of authority as constructed and contextual; of information as having value and of its creation as being a process; and of scholarship as being a conversation (ACRL, 2015).

Standards in information literacy emphasize the ability to use both divergent and convergent search strategies, but also to seek multiple perspectives when gathering and assessing information (ACRL, 2015). Whereas it is generally assumed that exposure to peers' ideas is valuable because it help diversify students' own ideas and expand their thinking, this exposure can also help refine and reinforce their existing understanding. For example, in a previous study, we examined the ideas students drew from their peers during a science inquiry unit, and the effects these had on their later written scientific explanations (Matuk & Linn, 2014). We found that students who sought peers' ideas that were redundant to their own were more likely to produce better quality explanations than students who sought ideas that diverged from their own. It was hypothesized that seeking redundant information amounted to refining one's own thinking, and imparted the benefit of learning by self-explanation (Roy & Chi, 2005). Meanwhile, other students may have sought diverse ideas because they were still exploring possibilities, and had not yet determined the key ideas necessary for a normative explanation. Thus, being drawn to divergent ideas may have been a red flag for students who required more conceptual guidance. These findings suggest there is more to know about which learners benefit from one strategy over the other, and when.

Two questions are pertinent, both for their relevance in designing and understanding the role of technology in supporting collaborative science inquiry, and in understanding the role of public knowledge repositories in general information literacy. One question is: What is the benefit of seeking divergent vs. convergent ideas on students' understanding? The impacts of each approach will gauge students' abilities to select and apply relevant information to a task. A second question is: What benefit do students perceive in exchanging ideas with peers? Their perceptions will gauge students' abilities to value others' ideas, as well as to recognize the need to evaluate others' contributions, which will vary in usefulness and relevance according to

the task. Both questions address students' awareness of their participation in an information-sharing community, and of the responsibilities this entails with respect to handling information.

Research questions

In this study, we ask what explicit instruction to seek contrasting vs. confirming points of view might reveal about the value of each approach. We investigate the impact on students' understanding when they are prompted to draw upon their peers to either diversify or reinforce their own ideas. Specifically: (1) How do students view the impact of their peers' ideas on their own understanding? (2) How do students revise their answers in response to their peers' ideas? and (3) How does diversifying vs. reinforcing ideas impact students' general conceptual understanding of a given topic?

WISE and the Idea Manager

We investigated these questions in the context of the Web-based Inquiry Science Environment (WISE). WISE is an open-source learning environment that offers a platform for authoring multimedia-rich units, and for monitoring, grading, and giving feedback on student work (Slotta & Linn, 2009). A library of adaptable classroom-tested middle and high school science inquiry units is available at wise.berkeley.edu.

This study uses the Idea Manager, a tool within WISE designed to promote the collaborative exchange of ideas during online science inquiry units (Matuk & Linn, 2014). Based upon the Knowledge Integration (KI) pattern of instruction, the Idea Manager guides students in integrating their prior fragmented ideas into a coherent understanding, first eliciting students' existing ideas, and then iteratively guiding them in organizing, distinguishing, and reflecting upon those ideas (Linn & Eylon, 2011). The tool thus emphasizes the development of information literacy by encouraging students to meaningfully organize and synthesize information from various sources, to monitor gaps in understanding, and to draw conclusions based on the interpretation of information gathered (ARCL, 2015). The Idea Manager scaffolds this process by breaking it down into manageable steps, providing a persistent space within which students can document their prior and existing ideas (Figure 1, left), share them with their classmates (Figure 1, right), and organize them as they prepare to write an explanation (Figure 2). WISE meanwhile logs the content of students' ideas; when these were added, shared, revised, or deleted; and with whom they were exchanged. Thus, in addition to scaffolding students' collaborative inquiry, the tool also provides a record with which researchers can examine students' developing understanding (Matuk & King Chen, 2011), including the role of peers.



Figure 1. Left: Interface from Mitosis for adding ideas to the Private Basket. Right: Interface from Mitosis for selecting ideas from the Public Basket

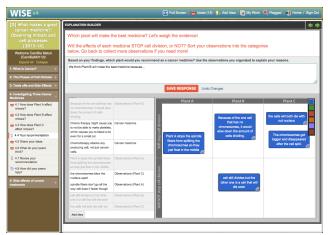


Figure 2. Interface from *Mitosis for* sorting ideas before recommending an effective cancer medicine

Methods

Participants

Participants were the 144 students across five class periods taught by one Grade 7 science teacher. The school was located on the west coast of the United States, and served a diverse but affluent student population. The teacher had more than 6 years of experience teaching with WISE, including previous versions of *Mitosis*.

The Mitosis unit

We integrated the Idea Manager into a middle school life sciences unit freely available at wise.berkeley.edu. In *What makes a good cancer medicine?: Observing mitosis and cell processes* (aka, *Mitosis*), students worked in pairs to explore videos, animations, and microscopic imagery of dividing cells as they learn about cancer and the phases of cell division. Throughout the unit, students used the Idea Manager to collect their observations, exchange ideas with peers, and sort ideas by dragging and dropping them into categories to prepare their written recommendations (Matuk & Linn, 2013). As a culminating activity, students examined separate animations of three dividing cells, each treated with a different plant-derived cancer treatment, and compared these to normal cell division. Students then refined an argument for the most effective cancer medicine based on their observations. For whichever option they chose (neither one being more or less correct), students were asked to write recommendations that integrated ideas about the roles of cell structures in the phases of cell division, the mechanism of cancer, and the action of an effective cancer medication (i.e., to stop cell division).

Study design

The study design is as follows (Figure 3). All students spent eight consecutive school days working in pairs to complete the *Mitosis* unit while their teacher and a researcher circulated the classroom to offer assistance as needed. The teacher also led whole class discussions each day to provide conceptual and logistic guidance.

Throughout *Mitosis*, all student pairs collected ideas in their *Private Baskets*, and organized and used these to support written recommendations for which of three plants would make the most effective cancer medicine. Students were then encouraged to contribute the ideas they used in their recommendations to a *Public Basket*, which was visible to their classmates. Students were then asked to visit the *Public Basket* and to select at least one of their peers' ideas to add to their *Private Baskets*.

Students were divided by class period into two groups. (Although this produced an uneven number of students in each group, we favored this approach because it made the job of grading students' work easier for the teacher.) Students in the *Diversify* group (Periods 2 and 5, N=59) were prompted to select ideas they did not already have. Students in the *Reinforce* group (Periods 1, 3, and 7, N=85) were prompted to select ideas that supported their existing ideas. All students were then encouraged to revise their initial recommendations based on these newly added ideas. Before advancing through the unit, students were asked to compare and contrast the new ideas with their existing ideas, to articulate what they modified on revising their recommendations, and to explain how their peers' ideas helped improve those recommendations.

Students spent an additional two days—one before and one after the unit—to individually complete a pre and posttest. Items on these tests were designed to measure conceptual understanding of the mechanisms of, and the relationship between cancer and cell division. Students were asked to order images and explain the

importance of specific phases of the cell cycle, and to propose and explain the effect of an effective drug based on their understanding of cancer and mitosis. One item was designed to capture students' abilities to evaluate new vs. existing ideas when constructing scientific explanations. This item asked students to select from a range of given ideas, one that they would add to an existing repertoire of ideas that would help create a complete explanation for the role of spindle fibers in cell division.

In addition to the written responses to the embedded items and pre and posttest assessments, we also asked for students' impressions of the unit upon their completion of it. In an online survey, we specifically asked students what they liked best about the unit, and what they felt could be improved.

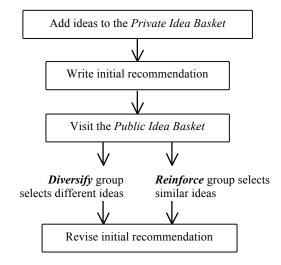


Figure 3. Study design, showing the sequence of activities throughout the Mitosis unit

Data and analyses

Measuring the perceived and actual impact of peers' ideas

To measure students' perceptions of the impact of their peers' ideas on their thinking, we scored the embedded items, in which students reported what they changed in their initial recommendations, and how they felt their peers' ideas helped improve their responses. Our scoring rubric had four levels, which ranged from reports of no effect of their peers' ideas, to a reinforcement of existing ideas, to reports that peers' ideas encouraged elaboration of existing ideas, to reports that peers' ideas entirely changed students' initial points of view (Table 1). We used a similar rubric to measure the actual impact of peers' ideas on students' understanding. Based on the differences between the initial and revised recommendations, scores ranged from peers ideas having no impact (i.e., students made no revisions to their recommendations), to having changed students' initial thinking (Table 2).

Table 1: Rubric for measuring the perceived impact of peers' ideas on students' revisions

Score	Description	Example			
1	No change. Students report making no changes to the content and wording of their initial recommendation.	we did not change our recommendation it stayed the same			
2	Increased confidence in existing ideas. Students report altering the wording without changing the content of their recommendation.	We didnt change our opinion about plant A being the best medicine but looking at the other ideas we grew more sure because it increased our knowledge of the plant.			
3	Detail added. Students report including new information that elaborates without changing the content of their recommendation.	the thing that we changed about our recomendation based on the ideas we got from the public idea basket is that we got more information to explain what happened to the cell when it was treated with plant b			
4	Major changes. Students report changing their initial point of view.	We changed our guess o(f) which plant to use. We saw others' ideas and thought that they made more sense. Plant B suddenly felt better than Plant A.			

Table 2: Rubric for measuring the actual impact of peers' ideas on students' revisions

Score	Description	Example
1	No change. The	Initial: C-both of the cells die. We chose this one even though there is a
	revision maintains	chance of other cells dies. On the A plant, the cell become useless. On plant b,
	the content and	one cell dies, the other is still alive.
	wording of the initial	
	recommendation.	<i>Revised:</i> We want plant C because it kills the cell, so it cant multiply any more
	Some initial detail	
	may be lost on	
	revision.	
2	Reworded. The	<i>Initial:</i> I think its B because having no chromosomes is not as bad as not
	revision restates the	reproducing, or chromosomes non stop growing.
	content in different	
	words but maintains	<i>Revised:</i> we still think that plant b is most effective because the cell still
	the same level of	reproduces even though it has no chromosomes
	detail in the content	
3	Detail added. The	<i>Initial:</i> We think that Plant A will solve cancer because it stops the spindle
	revision elaborates	fibers from creating the two new cells. Therefore, mitosis is stopped and cells
	without changing the	won't divide as much. Because of that cancer will slow down and might finally
	content of the initial	be cured. But, there is also a possibility that Plant A will stop cell division
	recommendation.	forever. Also, Plants B and C still let the cells divide, but the medicine still
		affects the cell.
		<i>Revised:</i> We think that Plant A will solve cancer because it stops the spindle
		fibers from creating the two new cells. Therefore, mitosis is stopped and cells
		won't divide as much. Because of that cancer will slow down and might finally
		be cured. But, there is also a possibility that Plant A will stop cell division
		forever. Also, Plant B still creates new cells although one of the cells doesn't
		have a chromosome. Plant C also creates more cells even though they both get
		their nuclei bigger.
4	Major changes. The	Initial: We would use the plant A because it stops mitosis earlier than the
	revision reflects a	other, because it doesn't mess up the cell with its normal function. we would
	different point of	not chose plant B because it doesn't stop cell division it like mess the normal
	view from the initial	division and that can makes a worse problem. We didn't chose plant C because
	recommendation.	it stops mitosis to late, it mess around the process and it make's it worse and
		because they would be two different cells but without a nuclear membrane, and
		that is bad.
		Denie of We doubt that about D is the base we did by the state of the
		<i>Revised:</i> We think that plant B is the best medical treatment because in
		Anaphase one of the cells will not have chromosomes and that will kill one of
		the cells because every cell needs chromosomes to survive. Another reason is
		that after that happens the cell that doesn't have the chromosomes will die and
		we will keep with only one cell, then that cell will divide and it is better that
		only one cell divides than if the two divide, because you will get less cells after
		cell division so that medicine will control the cancer.
		We didn't chose plant A because plant A stops cell division so then the cell
		will not do mitosis again. It stops the spindle fibers from lining up the
		chromosomes, and that stopped mitosis, and if the cell does mitosis the same
		each time it does it, that will make the cell never do mitosis again. That will be
		bad for the body to function, because will wouldn't have cells to function.
		We didn't chose plant C because it does it very slow and it mess up the cell.
		It doesn't make Telophase and that is important for the cell to work in order. It
		will make that one cell have a nuclear membrane and the other one not and that
		is not good for the cell. The one that doesn't have the nuclear membrane it
		expands through the cell, and then it will function messily.
		That is why we chose plant B, it will be more effective and will not damage
		the cell.

<u>Measuring pre and posttest gains</u> We used unique Knowledge Integration rubrics to score each item of the pre and posttests. These 4-point rubrics credit responses that correctly link key ideas. One item, for example, asked students to "Explain the effect your drug would have on the different parts of the cell in that phase, and how this would help keep cancer growth under control." For complete normative responses, we sought at least three key ideas, including an understanding that an effective medicine would stop cell division, a mention of the organelles affected, and an explanation of how the medicine would disrupt the normal actions of those organelles. Responses that correctly linked these three ideas received full marks, while those that linked fewer ideas received fewer marks. We averaged the KI scores across all items to obtain overall pre and posttest scores for each student.

Findings and discussion

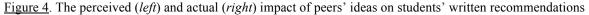
Perceived and actual impact of peers' ideas

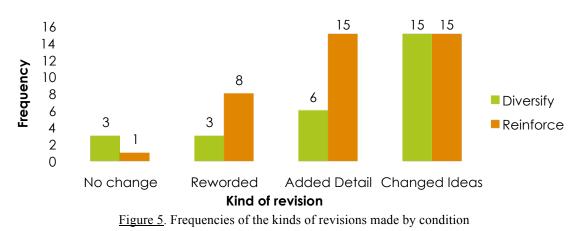
There was an overall significant difference between conditions in the perceived impact of peers' ideas (t=2.794, df=60.485, p=.007) (Figure 4, left). Specifically, students prompted to choose ideas different from their own were more likely to report these ideas as having helped them add details or modify their thinking (M=3.17). Meanwhile, students prompted to choose ideas similar to their own were more likely to report these ideas as having merely increased their confidence in their existing ideas, or as having had no impact on their thinking at all (M=2.65).

In measuring the actual impact of peers' ideas on students' revisions, it appeared that students who sought to reinforce their ideas also tended to view their revisions as simple rewordings or additions of detail to their initial recommendations compared to students who sought to diversify their ideas (Figure 5, right). However, this trend was not significant. That is, in spite of their perceived impacts, there did not appear to be any real impact on students' revisions between the *Diversify* (M=3.22) and *Reinforce* (M=3.13) conditions (t=0.388, df=47.425, p=.700) (Figure 5).

Together, these results suggest that peers' ideas had a bigger perceived than actual impact on students' thinking.







Pre and post test gains

There were significant differences in pre to post test gains between conditions (t=2.136, df=122.948, p=0.03). Students who drew on their peers to diversify their ideas performed better on the posttest (M=1.19) than

students who drew on their peers to reinforce their existing ideas (M=0.911). Thus, whereas the earlier results suggest there may not be any immediate or direct impact, prompting students to diversify as opposed to reinforce their ideas with those of their peers can ultimately promote more general conceptual understanding of the topic.

Other impacts of technology for sharing ideas

Collaborative tools such as the Idea Manager support a process of science inquiry that is more authentic than typical classroom science instruction. Such tools also have important motivational qualities. Indeed, students appeared to enjoy the ability to exchange ideas with their peers. As they commented in the survey at the end of the unit: "i liked how i could make an idea and share it with my class" and "I liked working together to combine our ideas."

For some students, the benefit of being able to access their peers' ideas appeared to extend beyond mere perception to actually encouraging revisiting and reconsideration of evidence in the unit, skills that are integral to science inquiry. As these students describe the impact of their peers: "they helped us see some mistakes, that the treated cells made, that we didnt see. Such as how in the plant C treated cell the chromosomes expanded and got bigger."

At the same time, access to a public repository of ideas also made it possible for students to be swayed by popular opinion. This student pair, who revised their response to recommend Plant B over Plant A, explains: "We saw more people that said the same thing about Plant B. They all were talking about one pair of chromosomes being killed. This felt better than A, which was the spindle fibers retracting. There were more Plant B than A explanations."

Conclusions and implications

This study investigated different ways of prompting the use of a collaborative tool to help students take advantage of their peers' ideas. In offering a public repository for ideas within an online science inquiry unit, we found that students perceived their peers as having greater impact on their thinking when encouraged to draw on their peers to diversify as opposed to reinforce their own ideas. In spite of students' perceptions, there were no impacts seen in students' actual revisions.

This finding may indicate an inability for students to realize the influence of new information on their understanding. Alternatively, it may be an artifact of the task design. Recall that an explicit prompt for students to either diversify or to reinforce their ideas was followed by a prompt to detail the impact of their actions. The formal context of this task may have led students to respond in a way that demonstrated that they followed the instructions, rather than to express recognition of real the impacts of their peers. Meanwhile, the fact that students who sought to diversify their ideas during the unit later showed greater pre to posttest gains than students who sought to reinforce their ideas, may indicate a real learning benefit in the diversification of ideas, at least among this group of students.

With more data, we might verify whether evening out the numbers of participants in each group would affect the significance of our findings. With more data, we might also quantify the observations made in the cases selected for our analysis. Nevertheless, our results suggest that explicit prompts to draw on a range of peers' ideas may encourage students to reconsider evidence and revise their own thinking. These are important practices to cultivate in developing science inquiry skills. Although these effects may not be immediate, they appear to have longer-term, and more general advantages. At the same time, there is evidence that some students are prone to be persuaded by the majority opinion rather than to objectively weigh peers' ideas. The implications of such behaviors over time, possibly in contributing to an increasingly homogenous public knowledge repository, deserve further investigation. What is clear is that the use of such repositories is thus not without caveats, and students may benefit from support in evaluating new information as they are exposed to their peers' ideas.

Further analyses will examine how the content of students' recommendations may have improved as a result of exposure to their peers' ideas, and what may have been the relative benefits of the kinds of revisions made as a result of diversifying vs. reinforcing ideas. Questions that remain for future investigation include: When in the inquiry process is it more helpful to diversify vs. reinforce one's ideas, and for which kinds of students (e.g., low vs. high prior knowledge)? How important is the perceived source of new information (e.g., classmates, teachers, or authoritative text)? Finally, what might be the teacher's role in moderating students' interactions within these public online spaces?

In all, this study reveals more about how tools such as the Idea Manager can help students draw on the knowledge of their peers to make sense of scientific ideas; improve literacy in general, as well as literacy in

science; and help students recognize the responsibility associated with being part of a community of knowledge builders.

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3D Tangibles Facilitate Joint Visual Attention in Dyads

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Abstract: We report results from a dual eye-tracking study around a Tangible User Interface (TUI). Participants (N=54) worked in groups of two and solved optimization problems on the TinkerTable, a TUI designed for students in logistics. The TinkerTable features tangible shelves that students can manipulate to build and optimize the layout of a warehouse while the system provides feedback with a projector above the table. Using mobile eye-trackers, we examined participants' visual coordination when solving those problems. We describe two contributions to the CSCL community: first, we propose a methodology for synchronizing two eye-tracking goggles and computing measures of joint visual attention (JVA) in a co-located setting. Second, we report preliminary findings suggesting that participants were more likely to have moments of joint attention when looking at 3D, realistic objects compared to 2D, abstract ones. JVA was also found to be a significant predictor of students' learning gains and performance during the optimization tasks. We discuss implications of these findings for supporting interactions around a TUI.

Keywords: Tangible user interface; eye-tracking; joint attention.

Introduction

A plethora of work suggests that Tangible User Interfaces (TUIs) are beneficial for collaboration in co-located settings (reviewed in Dillenbourg & Evans, 2011). Falcao and Price (2009), for instance, identified the constructive role of interferences in tangible learning environments: they found that sharing physical objects creates opportunities for verbal negotiation and conflict resolution, and that the "present at hand" nature of the tangibles supports a balanced level of participation. Additionally, several researchers proposed frameworks for conceptualizing interactions around interactive tabletops: Hornecker and Bur (2006), for instance, proposed that TUIs are different from GUIs (Graphical User Interfaces), because they provide tactile feedback, are embedded in real space, allow for embodied interactions and combine the expressiveness of both virtual and physical material to facilitate collaboration between users. While those contributions are important stepping-stones toward understanding users' interactions around a TUI, few empirical studies describe clear quantitative differences between small groups of users. Most studies are qualitative (e.g., Falcao & Price, 2009; Hornecker & Bur, 2006) or adopt a high-level perspective by using a rating scheme for the entire collaborative episode (e.g., Schneider, Jermann, Zufferey & Dillenbourg, 2011).

The goal of this paper is to close this gap by providing highly granular data on users' visual coordination around a TUI. We describe two contributions: first, we propose a methodology for synchronizing two eye-tracking goggles and computing measures of joint visual attention in a co-located setting. Second, we report preliminary findings suggesting that participants were more likely to have moments of joint attention when looking at 3D, realistic objects compared to 2D, abstract ones. To our knowledge, this is the first study to quantitatively measure joint visual attention in a co-located setting using mobile eye-trackers.

Joint attention in collaborative settings

Joint Attention is a crucial mechanism by which people establish common ground. It is defined as "the tendency for social partners to focus on a common reference and to monitor one another's attention to an outside entity, such as an object, person, or event" (Tomasello, 1995). Joint attention has been shown to be associated with higher quality of collaboration in multiple settings, both qualitatively and quantitatively. For the focus of this literature review, however, we will limit ourselves to eye-tracking studies even though there is a rich literature on joint attention from multiple fields (developmental psychology, education, social psychology). Richardson and Dale (2005), for instance, asynchronously recorded a speaker and a listener and measured their gaze with an eye-tracker; they found that the degree of gaze recurrence between speaker-listener dyads (i.e., the proportion of times that their gazes are aligned) was correlated with the listeners' accuracy on comprehension questions when

watching the video of the speaker. In a dual eye-tracking setting, Jermann, Mullins, Nuessli and Dillenbourg (2011) described how "good" programmers tend to have a higher recurrence of joint visual attention when having productive interactions compared to less proficient programmers. Schneider and Pea (2013), using two synchronized eye-trackers, showed that students who could see the gaze of their partner in real time in a remote collaboration outperformed their peers on a subsequent learning test compared to a control group; furthermore, learning gains were correlated with higher recurrence of joint visual attention. Finally, Brennan et al. (2008) studied the effect of shared gaze and speech during a spatial search task; they found that the shared gaze condition was the best of all. It was twice as fast and efficient as solitary search, and significantly faster than other collaborative conditions.

Due to space constraints, we will not exhaustively review the literature on joint attention. However, this phenomenon has been extensively studied in various fields and we can confidently say that joint attention is crucial for productive interactions between people of all ages. Additionally, the studies mentioned above suggest that eye-trackers are promising tools for understanding the factors that support a productive collaboration. In the next section, we discuss the relationship between tangible interfaces and joint attention.

Tangible interfaces and joint attention

To our knowledge there is no existing work connecting tangible interfaces and joint visual attention. Perceptual psychologists, however, have been studying the effect of physical stimuli on people's cognition for a long time. Farah, Rochlin and Klein (1994), for instance, asked subjects to recognize various 3D shapes. In one condition, they were presented with filled potato chip-like shapes. In another condition, subjects only saw their contours as wire frames. They found that participants were more accurate at remembering and recognizing shapes from the first category. This suggests that filled shapes contain perceptual information that can be used to facilitate visual recognition. In a meta-analysis, Sowell (1989) looked at 60 studies investigating the benefits of using manipulatives vs. pictorial material for teaching mathematics; she found that the long-term use of concrete material increased students' achievement and improved their attitude toward mathematics. Regarding verbal skills, Glenberg et al. (2004) asked children to read a text while manipulating toy objects (e.g., a barn, a tractor, a horse) to simulate the actions described in the text. Compared to a control group without access to those objects, this intervention resulted in markedly better (vs. rereading) comprehension of the text material. While many more studies have examined the effect of physical objects on people's cognition, it seems that in some contexts at least, tangible material has a positive effect on memory, problem-solving strategies, comprehension and learning. It is an open question whether such benefits transfer to social interactions. The goal of this paper is to explore this question in more detail using empirical measures. In the next section, we describe our experiment and dataset.

Experimental data

In this study we compared the effect of interacting with 3D or 2D objects around a tangible interface. Students interacted with an interactive simulation of a warehouse (Schneider, Jermann, Zufferey & Dillenbourg, 2011). The TinkerLamp allows users to quickly build and evaluate small-scale warehouses, thanks to a simulation projected on top of the model (Fig. 1). This learning environment has been adopted in several schools in Switzerland and is a robust pedagogical tool for teaching concepts in logistics. In this study, students' task was to analyze and optimize layouts for several warehouses while wearing eye-tracking goggles. In one condition, half of the participants used physical, 3D shelves (Fig. 1, right side); in another condition, shelves were represented by 2D paper rectangles (Fig. 1, left side). This manipulation allowed us to better control for the "representational effect" of 3D tangibles: the first group saw the warehouse as a small-scale model with realistic shelves, whereas the second group saw to a more abstract perspective with flat rectangular pieces of paper.

Methods

Subjects

Fifty-four apprentices in logistics participated in the study (28 in the "tangible" condition, mean age = 19.07, SD = 2.76; 26 in the "paper" condition, mean age = 17.96, SD = 1.56). Due to the vocational domain, few women participated (7 females; 4 in the "tangible" condition, 3 in the "paper" condition). All students who took part were following a vocational training in logistics: 16 first-year, 16 second-year, and 22 third-year (N=54).

Experimental design

We used a between-subjects experimental design with two conditions (Fig. 1): participants either worked with 2D paper shelves or 3D tangible shelves. We counter-balanced students' expertise between the two conditions: 8

first-years, 8 second-years and 12 third-years were assigned to the "tangible" condition; 8 first-years, 8 second-years and 10 third-years were assigned to the "paper" condition.

Procedure

The experiment was conducted in a private room of a Swiss professional school over a 4-day period. Participation was non-mandatory and did not count towards a grade. Upon arrival, the experimenter welcomed participants and asked them to complete a pre-test. The experimenter then told the students that their first task would be to individually memorize a warehouse layout for one minute and rebuild it from memory (Fig. 1, first row). Participants were then provided with the correct size of the warehouse—24 shelves, 2 docks—and were asked to individually recreate the layout. In the next activity, the experimenter told the students that they would have to discuss 3 layouts for 10 minutes (Fig. 1, middle row) based on three criteria (e.g., "In which warehouse would you prefer to work?", "Which warehouse optimizes space? Why?", and "Which warehouse minimizes the average distance from each shelf to the docks? Why?"). Finally, the experimenter provided them with two design principles about an efficient warehouse layout (in terms of optimizing storage space and of the average time to pick up an item from a shelf). For the last task, participants were instructed to use those principles to build their own warehouses and they used the interactive version of the TinkerLamp (Fig. 1, last row). They had 6 minutes to optimize storage space (e.g., insert as many shelves as possible) and 4 minutes to minimize the average distance to the docks by keeping only 9 shelves in their warehouse. Finally, participants completed a post-test (similar to the pre-test, except that the warehouse models were slightly different).

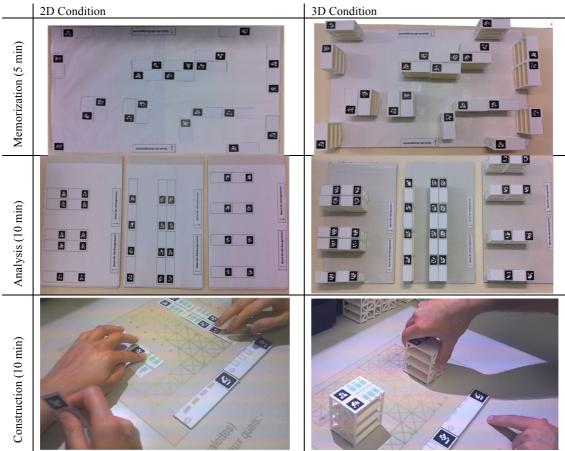


Figure 1. Our three experimental tasks: 1st row shows the layout participants had to memorize; 2nd row the contrasting cases students had to analyze; 3rd row the TUI for the construction task.

Material

The stimuli for each task are described in Figure 1. The learning tests had 4 questions: we asked students to 1) estimate the minimal distance between two shelves for a forklift to load up a pallet; 2) optimize the average distance between the docks and shelves of a given warehouse by correctly positioning two docks (arrivals and shipment); 3) optimize the average distance between the docks and shelves, except that the two docks were

already positioned and participants had to move two shelves to minimize the distance to the docks; 4) select good design principles for both maximizing space and minimizing the average distance to the docks from a multiple-answer question.

Coding

For the memory task, we counted the number of shelves and docks in the correct location as a retention score. For the optimization task, the TinkerLamp provided us with two measures of performance: the number of accessible pallets and the average distance to the docks. Additionally, students' answers to the learning tests were evaluated as follows: for the 1st question (estimating the minimal distance between two shelves to load up a pallet), participants received 1, 2, 3 or 4 points depending on the accuracy of their measurement. Answers below the minimal distance earned 0 points. For the 2nd and 3rd question, an optimal arrangement was worth 4 points. Points were deducted based on their (dis)similarity with the best answer. Question four and five (multiple-answer question) were evaluated as right or wrong. Perfectly answering the test was worth 20 points. Learning gains were computed by subtracting the score of the pre-test from the score of the post-test.

Experimental results

Using a multivariate analysis of variance (MANOVA), we found that participants in the "tangible" condition outperformed the participants in the "paper" condition for the memory task: F(1,52) = 4.48, p = 0.039 ("paper" condition: mean = 14.08, SD = 4.23; "tangible" condition: mean = 16.21, SD = 3.14). Students also built more efficient warehouses with the tangible version of the TinkerLamp, both for the space optimization task: F(1,25) = 16.79, p < 0.001 ("paper" condition: M = 11.69, SD = 2.25; "tangible condition: M = 15.29, SD = 2.30) and for the distance optimization task: F(1,25) = 12.01, p = 0.002 ("paper" condition: M = 8.73, SD = 2.12; "tangible" condition: M = 6.61, SD = 0.84). Finally, participants in the "tangible" condition had higher learning gains compared to the participants in the "paper" condition: F(1,52), 5.21, p = 0.027 ("paper" condition: M = 0.12, SD = 3.6; "tangible" condition: M = 2.5, SD = 4.04). Since those results are not the main focus of this paper, please refer to (Schneider, 2014) for a discussion of those findings.

Eye-tracking analysis

Participants wore non-invasive mobile eye-trackers during the three experimental tasks. The models used were 2 SMI Eye-Tracking Glasses (ETG) with binocular pupil tracking at 30Hz. Those units are lightweight (75gr.) and can easily be used for hour-long experimental sessions. We also used the scene camera (1280x960 pixels) to do fiducial tracking and synchronize the two devices. For this paper, we limit ourselves to the eye-tracking data generated during the second task. Students did not manipulate the shelves (but merely had to analyze the layouts and identify good design principles), and there was no virtual information overlaid on the tangibles. This step was 10 minutes long, meaning that our dataset contains 30 gaze points * 60 sec. * 10 min. (=18'000 data points) for each student, and almost 1 million data points for this activity across all participants.

Methodology for capturing joint attention in co-located settings

Working with mobile eye-trackers is challenging. Compared to standard eye-tracking setups, there is no predefined area of interest (AOI): participants are free to look 360 degrees around; they are not limited to the AOI defined by a computer screen. Thus, one requirement of our study was to have a "ground truth" to remap participants' gaze. Another requirement was to have reference points from both perspectives to compute a homography between what students saw and our ground truth (a homography is a mathematical operation that projects a point from a first plane to a second plane, using a minimum of 4 points known in both planes). A last requirement was to be able to synchronize the two eye-trackers by analyzing the videos generated by the scene camera. For the analysis task considered in this paper, the ground truth was easily defined: we simply took a picture of the three warehouses in each condition (Fig. 1, middle image). For the reference points, we used the fiducial tracker engine from the TinkerTable. We analyzed the frames of the videos generated from the eye-tracking goggles and generated log files with the location of each shelf detected in every single frame. We then used this information to remap the gaze of each subject on the ground truth using a homography. Lastly, we synchronized the two eye-tracking datasets by showing a special fiducial at the beginning and end of each activity: this provided us with a visual "hand clap" to synchronize both eye-trackers.

We spent a significant amount of time sanity checking our analyses by producing videos reconstructing the scene with both the students' perspectives and their gazes remapped onto the ground truth. Figure 2 (left side) shows one frame from such a video: the top and bottom images show the perspectives from the students, with their gaze in yellow and blue. Shelves captured by the TinkerLamp fiducial engine are shown in red. Lines between the student's perspective and the ground truth represent the points used for the homography. Each shelf

provides four points (i.e., the corners of the fiducial marker). It should be noted that the fiducial engine does not perfectly capture all the tags. To make sure that we had enough data for data analysis after the homography, we show the number of data points left for analysis at the end of the process (Fig. 2, right side). In general, $\sim 10\%$ of the data was lost after the homography, either because students were looking away from the table or because no fiducial markers were detected. For instance in Fig. 2, if no shelf had been detected from the perspective of the left participant, we would lose this data point because no homography could be computed – we would not have any points in common with the ground truth, and thus wouldn't be able to remap the participant's gaze onto it.

ant			Group	Data Points Captured	After the Homography
Left Participant		Number of Fixations	Tangible	6295.5 (1383.92)	4817.21 (1169.32)
		Number of	Paper	6722.12 (1472.68)	5953.96 (1369.55)
Ground Truth		f Saccades	Tangible	2360.07 (701.94)	1794.86 (768.01)
_		Number of Saccades	Paper	2414.92 (775.68)	2149.48 (869.47)
Right Participant	50px	Number of Blinks	Tangible	5439.46 (1455.97)	4250.57 (1188.4)
Rigl		Numt	Paper	5274.0 (1043.05)	4800.56 (1012.79)

<u>Figure 2</u>. Left side: one frame of our video analysis, used as a sanity check. The top and bottom images show the perspective from the students; the middle image shows the ground truth used to remap both gazes. Right side: Average number of data points for each student and type of gaze event (Fixation, Saccade, Blink). Standard deviations are shown in parentheses. Data retained after the homography is shown in the last column.

Computing a metric for joint visual attention

There are two main parameters to consider when measuring joint visual attention from eye-tracking data. First, participants' visual attention is rarely perfectly synchronized. In a foundational study, Richardson and Dale (2005) looked at the coupling between a speaker's and a listener's eye movements and found that a listener's eye movement most closely matched a speaker's gaze with a delay of 2 seconds. A second parameter to consider is the threshold for the distance between two gazes to qualify as 'joint attention'. Jerman, Mullins, Nuessli and Dillenbourg (2011) used a radius of 70 pixels with participants looking at a computer screen, but the size of the ellipse depends on the distance of the participants' eyes to the plane they are looking at. We build on those results to compute our own metric of joint attention: first, we looked at each gaze point from the first participant

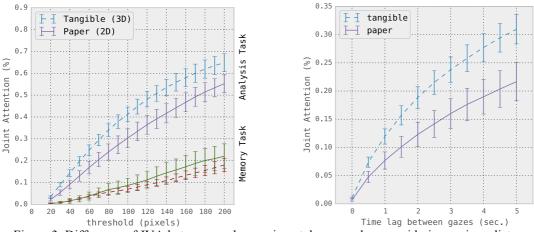
and tried to find a corresponding point from the second participant using different time windows (+/- [0,5] sec.; see Fig. 3, right side). Second, we tried radiuses between 10 and 190 pixels (Fig. 3, right side), where a threshold of 50 pixels corresponds to the shelf width. To facilitate interpretation, we show those values on the ground truth (in green on the bottom left side of Fig. 2): a distance of 50 pixels corresponds to the width of a shelf and 100 pixels to its length. We show below (Fig. 3, left side) the percentage of joint attention for each experimental group (y-axis) with different thresholds (x-axis). Finally, we also computed similar measures of JVA for the memory task (Fig. 3, left side), which provides us with a baseline showing the level of joint attention when two students looked at the same plane without collaborating. The rationale for this comparison is that there may be a bias for students to look at 3D shelves more often, which would artificially increase the likelihood of achieving joint attention (regardless of the collaboration between students).

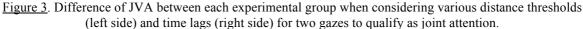
Since the number of data points varied widely between participants (see the standard deviation reported in table 1), we divided our measure for joint attention by the total number of gaze points of a participant to obtain a *percentage* of joint attention over the entire activity. This prevented us from inflating the joint attention score of a student that had more data points captured. Finally, we discarded blinks and saccades and only focused on fixations (i.e., the pause of the eye movement on a specific area of the visual field). The eye-tracking software (SMI BeGaze) automatically detected these three events (i.e., fixations, saccades, blinks).

Eye-tracking results

Using different thresholds (i.e., distance between two gazes) for measuring joint attention

As a first pass, we used a threshold of 50 pixels for the distance between two gazes to qualify as joint attention, and a time window of ± -2 seconds as advised by Richardson and Dale (2005). Students in the 3D condition had significantly more joint attention compared to the students in the 2D condition: F(1,25) = 4.98, p = 0.04, Cohen's d = 0.91 (for the 2D condition, mean=0.12, SD=0.07; for the 3D condition, mean=0.19, SD=0.07). In other words, students in the 2D condition gazed at the same location 12% of the time while students in the 3D condition jointly looked at the same area 19% of the time. Results were comparable when considering larger thresholds (see the non-overlapping error bars in Fig. 3, left side). For instance, we found similar results when using 100 pixels as a threshold: F(1,25) = 5.64, p = 0.03, Cohen's d = 0.97 (for the 2D condition, mean=0.25, SD=0.12; for the 3D condition, mean=0.36, SD=0.10). For the memory task, students in the 2D condition were more likely to achieve JVA, though this difference is not significant at any threshold (F < 1).





Using different time windows (i.e., the lag between two gazes) for measuring joint attention

In this section, we explore different time lags between two gazes to qualify as joint attention. Using a delay of +/-2 sec., we found that students in the 3D condition had significantly more joint attention compared to the students in the 2D condition (p < 0.05, as reported above). Results were comparable using different time windows (see the non-overlapping error bars in Fig. 3, right side).

The predictive value of joint visual attention

The JVA metric was predictive of students' performance on the subsequent optimization tasks: r(24) = 0.431, p = 0.028, which suggests that joint attention was associated with a better understanding of design principles for

optimizing warehouse layouts. When computing correlations for 1^{st} , 2^{nd} and 3^{rd} year students, we found different effects. Regarding 1^{st} and 2^{nd} year students (grouped together), joint attention was correlated with students' performance during the first optimization task (optimizing space): r(13) = 0.59, p = 0.021 and learning gains r(16) = 0.423, p = 0.051. For 3^{rd} year students, joint attention was correlated with students' performance at the second optimization task (optimizing distance from the shelves to the docks): r(9) = 0.618, p = 0.043 and not with learning gains r(9) = 0.101, p = 0.768. Those results show different dynamics of collaboration as students become experts, and suggest differentiated effects of a 3D TUI on different samples of students.

Finally, we report an anecdotal result that needs to be confirmed by future analyses. We rated students' quality of collaboration using Meier, Spada and Rummel (2007) rating scheme (note that this measure has not been double-coded by a second judge, which is why we mention this finding as anecdotal). A researcher coded the entire collaborative episode using a five point scale on the following eight dimensions: sustaining mutual understanding, dialogue management, information pooling, reaching consensus, task division, task management, technical coordination, reciprocal interaction, individual task orientation. Additionally, an overall score was computed by averaging ratings across all these dimensions. We found the percentage of joint attention to be significantly correlated with students' overall quality of collaboration: r(24) = 0.432, p = 0.027. More specifically, joint attention was significantly correlated with students' tendency to properly manage the group dialogue r(24) = 0.427, p = 0.03, reach a consensus r(24) = 0.517, p = 0.007 and equally divide work between members of the group r(24) = 0.424, p = 0.031. For comparison, Schneider and Pea (2013) performed the same analyses in a remote collaboration and found a significant correlation between joint attention and collaboration (more specifically, at sustaining mutual understanding, reaching a consensus, managing time and pooling information). This finding replicates previous results showing that joint attention can act as a proxy for students' quality of interaction, and seems to reflect their ability to reach a consensus across different settings.

Discussion

This paper reports two contributions to the CSCL community. First, we describe a methodology for quantitatively capturing joint attention in a co-located setting: we suggest using visual "hand-claps" for synchronizing mobile eye-trackers, and advocate the use of multiple fiducial markers for remapping gazes onto a ground truth. Secondly, we present some early results on the effect of 3D tangibles on students' visual coordination: we found that 3D tangibles seemed to facilitate visual coordination between users, which in turn was associated with higher performances on an optimization task. We have two tentative explanations for this effect: first, 3D objects may have special qualities that 2D objects do not—like shadows, height, and a high level of realism; it is possible that the perceptual richness of the 3D tangible shelves act as "hot spots" that users can exploit to ground their communications. Secondly, it is also possible that 3D objects are simply bigger than 2D objects (in terms of the number of "pixels" they occupy in a visual field); this would make 3D objects more likely to attract attention when one's partner is moving a shelf. Those two hypotheses (quality versus quantity) are non-competing in the sense that both may be true. Future work should try to disentangle those two explanations by looking more closely at the eye-tracking data and the videos recorded during the study.

Additionally, we tried to control for the following confounding variable: it is possible that there is more gaze on 3D objects than on flat objects, and subsequently more chances for the two gazes to be on the same object at the same time in the 3D condition (regardless of students' interactions). Two observations seem to disconfirm this hypothesis: first we did not observe this bias when computing JVA during the memory task, when no collaboration was allowed. In fact, we saw the opposite pattern: students in the 2D condition exhibited slightly more gaze recurrence than students in the 3D condition (non significant difference). Secondly, we found a significant correlation between levels of JVA and our dependent variables (performance task, learning gains, quality of collaboration): this suggests that JVA is indeed an indicator of more productive collaboration, and not just the result of chance or a perceptual bias.

Certain limitations need to be mentioned. First, we did not study a tangible interface *per se*, but a feature common to most TUIs (3D versus 2D representations). It is unclear if our results will generalize to other settings where users can interact with physical objects. Second, detecting joint attention by looking at the distance between two gazes is arbitrary; in future analyses, we would like to detect joint attention on more specific AOIs (i.e., shelves or corridors). Finally, we only presented quantitative results; in the future, we plan to complement those analyses with qualitative observations. As a final note, we acknowledge that the one-on-one correspondence of joint visual attention with quality of collaboration is a bit simplistic. Joint attention can take many forms (e.g., a silent moment of JVA is fundamentally different from a moment of JVA accompanied by a discussion), which should be taken into account for future work. Kaplan and Hafner (2006), for instance, describe a taxonomy that distinguishes between JVA triggered by a salient event, coincidental simultaneous

looking, gaze following and coordinated gaze on an object of interest. We plan to use this taxonomy in future work to get a more nuanced understanding of the relationship between joint attention and students' interactions.

Conclusions and implications

This work opens new doors for studying collaboration in co-located settings. Mounted eye-tracking devices are becoming cheaper and more accurate, and we are starting to see attempts to build low-cost mobile eye-trackers. Those technological developments suggest that eye tracking could become ubiquitous in the near future, which motivates the need for developing theoretical and practical frameworks for capturing students' gazes in co-located settings. By nature, those settings are much interesting than a remote collaboration, because most of the interactions between students currently happen in a physical classroom. Furthermore, it has long been unclear whether results from remote social eye-tracking studies generalize to co-located settings. Our findings suggest that, indeed, a higher recurrence of joint attention is correlated with students' task performance, learning gains and quality of collaboration across settings. This further motivates the need to closely pay attention to this construct when considering interactions in small groups of students.

All in all, we believe that the methodology and results described above are promising building blocks for studying visual coordination (and more generally collaborative learning) in small groups of students. We are seeing a lot of potential in this sort of approach, and believe that interesting future work can build on this first attempt at quantifying joint visual attention in a co-located setting.

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Fostering Sustained Knowledge Building through Metadiscourse Aided by the Idea Thread Mapper

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Abstract: This study was conducted in two Grade 5/6 classrooms that studied electricity over a three-month period using Knowledge Forum. Classroom A used Idea Thread Mapper (ITM)—a timeline-based collective discourse mapping tool—to engage in ongoing metadiscourse to review collective advances and gaps. Classroom B did not engage in this reflective practice until near the end of the inquiry. The results show that members of class A had more comprehensive and coherent awareness of the various inquiry themes discussed by their community focusing on deep conceptualization of electricity. Informed by the reflective awareness, classroom A also engaged in more active and connected online discourse to address deepening issues and develop coherent explanations across different lines of inquiry.

Keywords: metadiscourse, Idea Thread Mapper, knowledge building, collective responsibility

Introduction

Education to cultivate creative knowledge practices needs to support a progressive, collective trajectory of inquiry sustained over a long term for productive effects (Engle, 2006; Hakkarainen, 2003; Zhang et al., 2014). Students engage in sustained inquiry and knowledge building discourse: They contribute diverse ideas to ongoing conversations and collectively advance the ideas through constructive criticisms, mutual build-on, and progressive problem solving, with new and deeper challenges identified as their understanding advances (Bereiter, 2002). To enable a progressive, collective trajectory of inquiry, classrooms need to give student ideas a public representation, as part of collective knowledge (Bereiter, 2002). Various collaborative environments have been created to give student ideas an extended social life beyond segmented tasks and activities, so the ideas can be continually revisited, improved, and built upon by community members for deeper understanding. Despite the above potential support, current online environments lack effective means to represent collective knowledge growing in extended discourse. With ideas distributed across individual postings and responses over time, it is hard for students to understand the conceptual landscape and trajectories of their collective work, causing short-threaded discourse that lacks connected deepening moves (Hewitt, 2001; Suthers et al., 2008).

This research explores classroom designs to foster sustained knowledge building using the Idea Thread Mapper (ITM), a timeline-based collective discourse-mapping tool created by our team to make collective trajectories in online discourse visible for ongoing reflection (see Figure 1 for a map of idea threads).

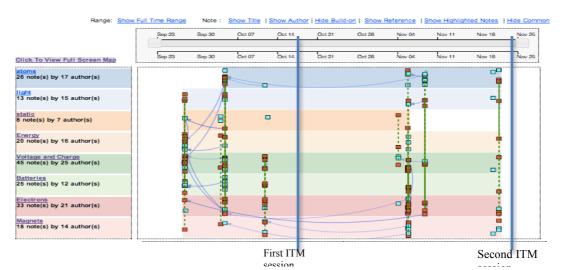


Figure 1. A map of idea threads created by a Grade 5/6 classroom studying electricity

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ITM Interoperates with Knowledge Forum (Scardamalia, 2002) and potentially other platforms for collaborative knowledge building. In these online environments, students contribute and build on one another's ideas in interactive discourse, with ideas presented in distributed postings (e.g. notes) and build-on responses. Beyond these micro-level representations, we introduced "idea threads" or "inquiry threads" (Zhang et al., 2007) as a larger, emergent unit of ideas in online discourse. Each idea thread is composed of a sequence of discourse entries (possibly involving several build-on trees) contributed by a subset of the members of a community to address a shared problem or discourse topic, such as batteries and other topics in Figure 1. ITM allows students to define focal problem-based topics and select important discourse entries addressing each topic. The discourse entries in each idea thread are displayed on a timeline with the authors and build-on connections identified. The knowledge progress in each idea thread is further made transparent by students through co-authoring a "Journey of Thinking" synthesis aided by a set of scaffolds (e.g., We want to understand, We used to think...we now understand..., We need to do more). Idea threads and thread-based syntheses are co-editable by members of the classroom, with each version recorded for later review. The collective knowledge of the community in a whole inquiry is further represented as clusters of idea threads (Figure 1) that address interrelated problems through connected efforts of the members. In Figure 1, each colored stripe represents an idea thread extending from the first till the last note contributed addressing its focal problem/topic. Each square represents a note. A blue line between two notes represents a build-on link. A dotted vertical line shows notes shared between different threads discussing interrelated issues. By examining this cluster of idea threads, students can reflect on their contributions, cross-thread connections, and weak areas that need deeper work.

Sustained knowledge building requires students to take on collective responsibility for progressively defining what they need to further understand as their collective understanding advances (Scardamalia, 2002). Students face the challenge to enact collective regulation of long-term knowledge building: to construct shared goals, formulate plans of actions, monitor collective progress and engagement, and adapt collaborative processes to optimize members' contribution to achieving their shared outcomes (Järvelä & Hadwin, 2013; Zhang et al., 2009). ITM-based designs support students' collective regulation of long-term knowledge building through metadiscourse: metacognitive conversations about the ongoing inquiry and discourse focusing on high-level decision making, including collective goal formulation, progress review, and co-planning (Zhang et al., 2009, 2014). Such metadiscourse is critical to knowledge building, but it is rarely observed in inquiry-based settings (Scardamalia, 2002; van Aalst, 2009). ITM-based metadiscourse is organized to support talk-organizing and talk-evaluating functions (cf. Vande Kopple, 1985): to frame and review ongoing discourse contributions based on shared focuses and goals, to monitor progress in each unfolding lines of inquiry, to synthesize insights and identify gaps and deeper actions. Through metadiscourse, students generate high-level reflective representations of their ongoing discourse to guide sustained inquiry and coherent discourse.

The current study is part of a multi-year design-based research to understand the operation of metadiscourse and its role in helping students co-monitor and advance their collective knowledge. In the first iteration, we conducted a set of studies in a Grade 3 and two Grade 5/6 classrooms. The results elaborated the process and benefits of ITM-aided metadiscourse, which helped fostering student awareness of collective progress beyond individual focuses and informing sustained and connected discourse to address deepening questions, leading to sophisticated explanations of complex issues (Zhang et al, 2013, 2014). However, these findings were generated through exploratory studies without cross-condition comparison. Also, the ITM-aided metadiscourse was implemented as a single classroom session. Further expansions need to organize it as a formative, ongoing effort while enabling easy connections between ITM-aided metadiscourse and ongoing online discourse. The current study, as the second iteration, aims to address these needs. Our research question asks: In what ways does such ongoing metadiscourse help students to monitor diverse inquiry themes evolving in their community's discourse and formulate connected, progressive discourse for deep understanding?

Method

Classroom contexts and implementation

This study was carried out in two Grade 5/6 classrooms, with 21 students in classroom A and 22 in B. The two classes were taught by two experienced teachers, respectively, each having multiple years of experience with facilitating inquiry. Students in each classroom investigated electricity over a 12-week period with two science lessons each week. Their work integrated whole class knowledge building conversations, individual and cooperative reading, student-directed experiments and observations, and so forth. Major ideas, questions, and findings were contributed to Knowledge Forum for continual discourse online. For cross-classroom comparison, the design of ITM-aided metadiscourse and reflection was implemented as an ongoing effort in Class A beginning from the third week of the electricity inquiry; such reflection was only systematically implemented in

Class B in the final phase of the inquiry in Week 9. This time-lag design allowed us to conduct detailed data analysis of Class A to elaborate the ongoing process of ITM-aided metadiscourse while enabling cross-classroom comparisons to examine the impact of ITM-aided metadiscourse on student knowledge building. The knowledge building work unfolded as a continuous process; for the purpose of data analysis, we identified three phases, as elaborated below.

Phase 1 (weeks 1-3), as the baseline

This phase extended from week 1 to 3 till Class A implemented its first ITM reflection session. Examining student interaction in this phase when ITM was not yet used in either classroom provided the baseline data about student knowledge building facilitated by the two teachers. In both classrooms students began their electricity inquiry with hands-on explorations of static electricity, circuit and conductors, and magnets. They discussed their findings in small groups and further shared their questions and ideas through whole class knowledge building conversations. Extending their face-to-face interactions, students wrote and built on one another's notes in Knowledge Forum to discuss their ideas, observations, and questions.

Phase 2 (weeks 4-8), as the focus of the data analysis and comparison

This phase extended from Class A's first ITM reflection session to its second ITM session till Class B conducted its only ITM session. Comparing student engagement in this phase between classroom A and B helped to examine the impact of ITM reflection on sustained knowledge building. By the end of the third week, students in class A had created 89 notes in their Knowledge Forum view. They conducted the first ITM session to review collective progress. The whole class made an initial pass to co-review their Knowledge Forum view (discourse space) projected on a screen to identify high-potential "juicy topics" that had been discussed. Students were then given a printout of their Knowledge Forum view, which served as a bridging artifact to support metadiscourse about their online written discourse. They worked in small groups to identify note clusters that discussed various topics, marking different clusters using different colors. The whole class then convened to discuss the topics identified, leading to the creation of a collective list of eight "juicy topics" highlighting problems related to batteries, static electricity, magnetism, electrons, atoms, voltage & charge, energy sources, and light. The students then formed into topic-based voluntary groups, each of which constructed an idea thread for a topic using ITM. Members of each group decided keywords to be used to search for related Knowledge Forum notes and found and selected the notes that addressed the focal topic. This session was concluded with a whole class conversation to examine the map of idea threads (see Figure 1 till the first ITM session) and reflect on community-wide advancement, cross-theme connections, and weak areas. Students realized that the different idea threads all have connections with electrical charges carried by electrons and protons. This fundamental understanding was later diffused to the inquiry and discourse about a wide range of specific topics such as static electricity, batteries, lightning, and so forth. With deeper inquiry and discourse carried out in the subsequent three weeks, students in class A conducted the second ITM reflection session in which they updated each idea thread by including new Knowledge Forum notes addressing the deeper issues (see the threads extended after the first ITM session in Figure 1). Consolidating their reflection, students further worked as small groups to create a "Journey of Thinking" synthesis for each idea thread using a set of scaffolds that highlighted problems of understanding, collective progress, and deeper issues.

Phase 3 (week 9-12), final research and presentations

Following similar procedures, students in class B implemented ITM-aided reflection to review their online discourse as idea threads and authored Journeys of thinking syntheses to summarize their advances and deeper issues. In the rest of the inquiry, students in both classrooms concentrated on classroom-based inquiry to understand the deep issues identified through ITM reflection and preparing final presentations to share new knowledge about these issues. With these efforts mostly enacted as face-to-face activities, students contributed a limited number of notes online in this phase. Therefore, we did not conduct statistical analysis for this phase.

Data analysis

Video analysis of the ITM-aided metadiscourse is reported in Zhang et al. (2015), which elaborates the processes of metadiscourse for ongoing regulation of knowledge building: to formulate shared focuses and goals as emergent from diverse discourse input; to review contributions, advances, and deeper issues in each line of work focusing on a high-potential topic; to examine clusters of idea threads and synthesize community-wide advances, connections, and challenges, and to plan deeper efforts as individuals and spontaneous groups to address the community's needs. The analyses in this paper focus on the role of metadiscourse to help students monitor diverse evolving themes of inquiry and formulate connected deepening discourse.

Content analysis of individual portfolio summaries

To examine students' reflective awareness and understanding of the various inquiry themes in their community's discourse space, we asked each student in classroom A and B to summarize what they had learned around the midpoint of the inquiry (after class A's first ITM session). Each student's summary was coded through content analysis (Chi, 1997). Specifically, two analysts first read the online discourse and observation notes of the two classrooms to identify various topics of inquiry mentioned in relation to the topics specified in the curriculum guidelines. They shared the identified topics and merged similar or closely related topics (e.g. atoms and electrons), with a final list of ten topics created (e.g. batteries, static electricity, voltage and charge, atoms). A primary coder then read each portfolio summary to identify utterances related to each of the focal topics. The ideas related to each focal topic were further coded based on epistemic complexity and scientific sophistication using coding schemes validated through our previous studies (Zhang et al., 2007). Scientific sophistication examines the extent to which students' ideas align with a scientific framework of electricity based on a four-point scale: 1 - pre-scientific, 2 - hybrid, 3 - basically scientific, and 4 - scientific. Epistemic complexity indicates students' efforts to produce not only descriptions of the material world, but also theoretical explanations and articulation of hidden mechanisms, which are central to the goal of science (Salmon, 1984). A five-point scale (1- topic term only, 2 - unelaborated facts, 3 - elaborated facts, 4 - unelaborated explanations, and 5 - elaborated explanations) was used to code ideas about each topic. Considering these two scales as ordered and continuous, we assessed the inter-rater reliability using Pearson correlation, which was found to be 0.88 for epistemic complexity and 0.89 for scientific sophistication between two independent coders.

Beyond student understanding of each individual topic, we analyzed the level of coherence in explaining different topics focusing on the nature of electricity. Borges and Horizonte (1999) identified increasingly complicated mental models about how electricity works: a general conception of electricity as the flow of energy often found among young students, a more informed conception focusing on positive and negative charges, a deeper explanation of the charges based on the movement of electrically charged particles, and the most complicated understanding of electricity as a field phenomenon. Deeper conceptualizations favor more coherent understanding of seemingly different topics that share the same mechanisms. In light of these mental models of electricity, we created a coding scheme (see Table 1) to categorize each student's explanations across topics such as electric circuits, conductors, batteries, current, and charges. Table 1 does not include electricity as a field phenomenon (category 4) because none of the students showed this understanding that is far beyond the level of Grade 5/6. Two raters independently coded 21 portfolio summaries resulting in an inter-rater agreement of 95.24% (Cohen's Kappa = 0.97 for this category-based coding).

Category	Description
0. No explanation	Basic facts or terms only, without explanations about how electric circuits work.
1. Electricity as flow of	Students describe batteries as the source of energy that provides electricity.
energy	Electricity flows through wires/conductors to the light bulb.
2. Electricity as positive	Students explain the flow of electricity in terms of positive and negative charges or
and negative	currents. For electricity to flow, the wires need to connect both positive and
charges/currents	negative terminals of the battery towards the bulb to form a closed circuit.
3. Electricity as	Students mention positive and negative charges and further understand them in
movement of electrically	terms of the movement of electrically charged particles including protons and
charged particles	electrons. Battery is seen as an active source of electricity by means of chemical
	reaction enabling the movement of electrically charged particles.

Table 1: Progressively more complicated explanations of how electric circuits work

Quantitative analysis of student contribution and interaction in the online discourse

Using the analytic toolkit underlying Knowledge Forum, we retrieved quantitative data about student note contributions and build-on links in each phase of the inquiry. Comparing the level of contribution and interactivity between the two classrooms especially for Phase 2 helped us to gauge the benefits of ITM reflection in sustaining active and connected knowledge building discourse.

Qualitative tracing of idea improvement in each idea thread as related to students' final presentations

To understand the specific ways in which ITM-aided metadiscourse fostered coherent efforts of sustained knowledge building, we qualitatively analyzed the online discourse in the idea threads organized by students in classroom A in comparison to the online discourse of classroom B. Following inquiry thread analysis (Zhang et al., 2007), we used each idea thread topic defined by students as a "tracer" to trace interactive ideas and

questions contributed to the online discourse over time before and after the ITM reflection sessions in relation to the classroom inquiry activities observed. For each idea thread, two researchers co-read the notes in a chronological sequence to develop an overall sense of visible idea-advancing changes. They further identified new questions and ideas in the online discourse before the first ITM reflection session, during ITM reflection in the ITM Journey of Thinking synthesis, in the online discourse after the first ITM reflection, as well as in students' final presentations sharing deeper knowledge about each topic. The ideas and questions were compared between the different phases of inquiry and linked across different idea threads to identify salient idea-advancing patterns by which students went beyond the existent information in their community to develop more advanced concepts and frame unfolding trajectories and directions to guide coherent contributions.

Results

Content analysis of student summaries

The content analysis of student summaries examined student awareness of the inquiry topics addressed by their community and their understanding of each topic based on epistemic complexity and scientific sophistication. Through ITM-aided reflection, students in classroom A were able to summarize more topics of inquiry about electricity (M = 5.89, SD = 1.63) than students in classroom B (M = 4.65, SD = 1.18) (F (1.37) = 7.51, p = .009). Specifically, classroom A had many more students summarizing understandings of abstract topics such as electrical charges and atoms (including electrons). The average scientific rating of students' ideas in both classrooms was between "3 - basically scientific" and "4 - scientific" without significant difference (p > .05). Students in classroom A articulated understandings of the various topics at a higher level of epistemic complexity (M = 3.94, SD = .58) than those in classroom B (M = 3.49, SD = .53) to explain the mechanisms, processes, reasons, and relationships beyond factual descriptions (F (1.36) = 6.51, p = .015).

We further coded the coherent explanations of students across specific topics based on progressively advanced models about how electricity works (Figure 2). The proportions of students coded for the different categories of explanations (see Table 1) differ significantly between the two classrooms ($X^2 = 16.03$, df = 3, p = .001). Classroom A had higher percentages of students giving advanced explanations that conceive electricity as negative and positive charges (category 2) carried by electrically charged particles (category 3). On the contrary, a majority of students in classroom B explained electric circuits at a general level as energy flow from the battery to the light bulb (category 1).

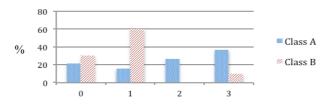


Figure 2. Percentages of students giving different explanations of electricity

Quantitative analysis of student contribution and interaction in online discourse

To gauge student contribution and interactivity in online discourse, we analyzed the number of notes contributed by each student and the percentage of notes in build-on links. Table 2 shows these two measures for each classroom in Phase 1 before ITM use and in Phase 2 after class A started its use of ITM (before class B used ITM). In Phase 1, students in class A contributed more notes to the online discourse in Knowledge Forum than those in classroom B (F (1,41) = 4.59, p = .038). There was no significant difference in the percentage of notes with build-on links (p >.10). These measures of note contribution and linking (build-on) in this phase were included as covariates in the analysis of variance of students' note contribution and linking in Phase 2. Informed by their ITM-aided reflection on their collective knowledge advances, gaps, and connections, students in class A wrote a significantly larger number of notes in Phase 2 than class B (F(1, 40) = 6.34, p = .016). A significant effect was observed for the covariate of student contribution rate in Phase 1 (F(1, 40) = 4.08, p = .05). Classroom A in Phase 2 also had a significantly higher percentage of notes with build-on links than classroom B (F (1, 40) = 6.29, p = .016), with a significant effect observed for students' note linking percentages in Phase 1 as a covariant (F (1, 43) = 4.45, p = .041). These results demonstrate that the ITM-aided reflection helped class A to sustain more active and connected knowledge building discourse.

Classroom	Phase 1: Week 1-3		Phase 2: Week 4-8		
Notes written per		% of notes linked	Notes written per	% of notes linked	
	student		student		
A: ITM Use after	4.86 (2.61)	37.19 (33.27)	3.57 (3.16)	35.00 (34.00)	
Week 3					
B: ITM Use Delayed	3.32 (2.01)	40.23 (29.87)	1.36 (0.67)	15.00 (22.90)	
till after Week 8					

Table 2: Contributions to the online knowledge building discourse (means and standard deviations)

Qualitative tracing of idea improvement across the idea threads

Deepening the quantitative analysis, we conducted qualitative tracing of each idea thread to identify salient ideaadvancing patterns by which the community went beyond existent contributions of individual students to develop advanced concepts and frame unfolding trajectories and directions of inquiry.

Conceptual "rise-above" and abstraction

As a primary pattern, students developed their idea trajectories by identifying emergent conceptual constructs as shared objects of inquiry to generate increasingly powerful explanations. The whole inquiry initiative began with student hands-on exploration of batteries, light bulbs, magnets, and static electricity. Students then interacted online to discuss initial observations, questions, and ideas, which became the starters of the idea threads about batteries, static electricity, energy sources, and magnets. Sustaining inquiry in these idea threads, students searched for conceptual explanations of the empirical facts that they had observed. Abstract conceptual constructs developed later became objects of inquiry in their own right, leading to the emergence of idea threads investigating electric charges, electrons, and atoms. For example, students' initial explanation about how batteries work assumed that there would be "mini batteries" inside the batteries to generate energy. This explanation was replaced with better theories, such as: "protons and electrons are...two parts of the battery" that carry positive and negative charges and that there are "a lot of chemical reactions" inside the battery. Interest emerged among the students to understand electrons, atomic structure and protons, and positive and negative charges. Similarly, students' online discourse on fabrics that cause static electricity came across the concepts of negative and positive charges. In the first ITM reflection session, students explicitly identified such abstract concepts as electric charges and voltage, atoms, and electrons as core topics of inquiry in their community. Through examining their map of idea threads (Figure 1), students noticed deep connections between these concepts and all the other idea thread topics and identified electrons, atoms, and charges/voltage as the areas that needed deeper exploration. Core questions were raised in the Journey of Thinking syntheses regarding these topics, such as: What makes electrons move? What is the connection between atoms and energy? How do atomic bombs work? These areas and questions of inquiry became the focus of the subsequent work. As Figure 1 show, the idea threads about charges/voltage, atoms, and electrons involved the most intensive discourse after the first ITM reflection in mid-October. Deep understandings were shared in students' final presentations that explained atomic structure and how positively and negatively charged particles interact.

Progressive deepening

Students further deepened and sustained their trajectories of inquiry by identifying productive deepening questions as progressive goals in each line of work for specialized investigation. Students in classroom A generated a diverse set of questions through initial hands-on explorations that caught their deep interest. On the basis of these initial specific questions, ITM-aided metadiscourse further fostered students' efforts to formulate deeper questions in light of major conceptual constructs emerged from their discourse, such as electrons and electric charges. ITM's feature of Journey of Thinking scaffolded student efforts to generate progressively deeper questions in light of their advanced understandings. Before class A's first ITM reflection, 38.55% of the notes contained questions, with 15.66% of the notes raising general wonderment questions focusing on broad issues (e.g. what powers a battery?) and 22.89% raising idea-deepening and elaborating questions (e.g. why isn't the iron attracted to the other side of the magnet?). The ITM-aided metadiscourse and reflection explicitly encouraged students to review their progressive questions and ideas in each idea thread and co-author Journey of Thinking syntheses. When co-authoring the Journey of Thinking synthesis for an idea thread as a group, the students discussed their existing questions and summarize the most important ideas learned (e.g. "magnets produce an invisible magnetic field ..."). They further selectively highlighted deeper questions to be addressed in each focal area ("we need to understand how magnets relate to electricity"). These deeper questions highlighted for different idea threads were later written on a piece of chart paper as a collective list of problems for their community. Students then formed into voluntary specialized teams to conduct focused research to address these issues. They authored individual and collaborative notes in Knowledge Forum to share findings while identifying even deeper questions. Among the notes written by class A in Phase 2 after its first ITM session, 36.84% raised questions, including 5.26% raising general wonderment questions and 31.58% addressing more specific, idea-deepening and elaborating questions (e.g. why are some metals magnetic and some not?) These showed more active deepening moves than class B that only had 22.22% of notes raising questions in Phase 2.

Conceptual connection and diffusion

As students worked on deepening questions and ideas in each area, they monitored cross-thread connections to advance the community's common ground understandings. Students engaged in reflective conversations to review connections across different idea thread themes, leading to the insight that "everything is connected... electrons are part of atoms and electrons have charge, and so charge is connected to atoms through electrons." This insight in cross-thread connections was further developed and reflected in the Journey of Thinking syntheses authored by student groups. When synthesizing "big ideas" in each idea thread, students mentioned electron movement in six out of the eight idea threads: "Everything is made of atoms. The atoms are made out of protons, neutrons, and electrons." "Electrons have a negative charge. It's always electrons that transfer onto your body when you rub your foot on the carpet." "Electrons moving create energy." The understanding of electrical charges in terms of the movement of electrons and protons was used to enrich the discourse across all the idea threads after the first ITM session, with 12.28% of class A's notes in Phase 2 (compared to 1.38% in class B) building cross-topic connections. Important insights were generated, including: "Electrons are the essence of charge. Atoms are the root of everything having to do with electricity." "Whenever you charge one thing positively, you are always charging the other object negatively. It's because the electrons move from one to the other." Atom (including electron) was the most frequently mentioned topic in the individual portfolio summaries, with 21 of the 22 students summarizing understandings related to this topic.

Discussion

Through ITM-aided metadiscourse, students in classroom A demonstrated more comprehensive awareness and coherent understanding of the emergent inquiry themes of their community. The iterative processes to review the ongoing knowledge building discourse for shared high-interest focuses, identify related contributions, and synthesize insights and challenges helped the members monitor the unfolding lines of inquiry focusing on core issues about electricity. This finding is consistent with the findings of our first iteration in this design-based research, showing that ITM-aided metadiscourse and reflection helped bring more themes of communal inquiry to the attention of the community members (Zhang et al., 2013). In a knowledge building community that encourages diverse expertise, each student needs to conduct focused (specialized) inquiry with peers to address a few of their communal topics while developing an awareness of the advances of the whole community beyond their own work (Zhang et al., 2007). ITM-aided metadiscourse helps students to address this need through collectively monitoring the unfolding lines of inquiry of their whole community, leading to broadened awareness of various inquiry themes and, more importantly, reflective understanding of cross-theme connections focusing on core conceptualizations (Figure 2).

With reflective awareness of the various lines of work in their community, students in classroom A engaged in more sustained and connected knowledge-building discourse online in the second phase of the inquiry. They contributed more notes to address deeper issues identified for each line of work, and their notes had more build-on links than those created by classroom B (Table 2). These results are also congruent with our previous findings suggesting an increased level of connectedness in the online discourse resulted from ITMaided reflection (Chen et al., 2013). The ITM-aided metadiscourse to review collective advances, challenges and connections has the potential to help sustain productive online discourse among students, which, in current practice, often lacks active connected contributions and deepening moves (Guzdial et al., 2001). As the qualitative tracing of idea threads suggests, the ITM-aided metadiscourse and reflection could enhance students efforts to continually go beyond existent contributions to "rise above" toward high-level conceptualizations, to generate deepening questions, and to build conceptual connection across different lines of inquiry. The inquiry process initially focused on concrete and tangible aspects of electricity, which needed to be explained using higher-level conceptual structures. The ITM-aided metadiscourse to review core topics of inquiry from the existing distributed discourse helped the students to explicitly define abstract concepts, such as electric charges and voltage, atoms, and electrons, as shared goals of research in their community, leading to intentional and intensive contributions to these areas. Through the ongoing metadiscourse and reflection, students further identified deeper questions and issues as informed by their updated understanding, which brought forth

deepening goals for progressive problem solving (Bereiter, 2002). These deepening goals served to guide individual and collaborative efforts to address these questions. The core concepts of electric charges and electrons were diffused to understanding different topics (static electricity, batteries).

In conclusion, the collective metadiscourse supported by ITM serves to represent and guide collective inquiry trajectories in extended knowledge building discourse. To better support reflective metadiscourse about unfolding threads of ideas, we are creating automated analysis to ease idea thread review and further make productive idea threads sharable across communities that learn from and build on one other's progress.

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Learning about Collaborative Design for Learning in a Multi-Surface Design Studio

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Abstract: This paper fuses research on CSCL and collaborative design for learning. Despite growing awareness in the CSCL community of the importance of design in teachers' work, there has been little empirical research on how such design is carried out, or how design for CSCL can be supported through the provision of better design tools and design methods. The paper offers an analysis of the work of four pairs of designers in our Multi-Surface Design Studio. These four dyads were completing a design task we set them, while simultaneously learning how to make good use of the various personal and shared digital tools, display surfaces and other resources in the studio. From observational and interview data, we show how collaborative design for learning needs to be understood as a complex, multiply-situated activity, in which design problem-solving, tools and space usage depend on the fluent deployment of intuitive knowledge about mutual awareness, shared perception, information persistence and movement.

Keywords: design for learning, teachers, technology, multi-touch, design, face-to-face collaboration

Introduction

Most established design professions rely on conventional forms for representing finished and in-progress designs. Many of these are graphical such as sketches and blueprints (Li et al., 2005). There are some penetrating analyses of these visual representations and their relations with design thinking and the tools used (Buxton, 2010). There is also strong evidence favouring *collaborative design*: to ensure that expertise which is distributed among different specialists can be combined, and to ensure that the different views of multiple stakeholders are addressed (Arias et al., 2000; Li, et al., 2005). In these more established design professions, use of computer-based tools to aid design is also commonplace, making it easier to work with graphical representations of design ideas and also to collaborate (Kvan, 2000; Li, et al., 2005). There has been a small vein of research on visual languages in educational design (Botturi & Stubbs, 2008) and a 30 year history of R&D on tools for educational design, but take-up of tools and methods by practitioners has been limited (Conole, 2013; Goodyear, 1997; Laurillard, 2012; McKenney, 2005; Prieto et al., 2014; Tennyson, 1994). And despite a renewed interest in teachers as designers within the CSCL community, coupled with a strong focus on design aids such as collaboration scripts, there is still little empirical research on how people use such tools and methods when designing for others's learning (Ertmer et al., 2013; Fischer et al., 2013).

This paper reports on a strand of our research which aims to find better ways of supporting educational design activity (design for learning) by: 1) iteratively prototyping a studio space customised for collaborative design; and 2) observing and analysing the work of users of that space. We have been guided by recent research in CSCL on forms of co-located collaborative learning that involve interactive surface devices, in increasingly richer ecologies: e.g. interactive whiteboards, tabletops, tablets, mobile devices (Evans et al., 2014). Interactive surfaces and spaces provide new opportunities for co-located collaboration as they are intrinsically designed as shared interfaces, allowing simultaneous input from multiple users and facilitating physical interaction, direct communication and mutual awareness (Evans et al., 2014). These are key factors for successful collaborative learning (Dillenbourg, 1998) and collaborative design (Thompson et al., 2013).

Specifically, we explore our participants' use of space and tools in the multi-surface design studio. The task we set them steered them towards using a multi-touch interactive table, but its use has to be understood in the broader ecology of other surfaces and other tools and resources available to them in the studio. We collected multiple streams of data (video, audio, log files of the application use, interviews and questionnaires, as well as the final designs produced by participants). The study involved four pairs of participants, with each pair (or dyad) having exclusive use of the studio during its design session.

The rest of the paper is organised as follows. The next section explains the approach we are taking in our research. It has some unusual qualities, which distinguish it from some more conventional approaches to developing and testing collaboration technologies. Then, we describe the multi-surface setting, present the empirical research conducted for this paper, draw some conclusions and make suggestions for further research.

Approach

The paradigm to develop our multi-surface studio draws on *design anthropology* (Gunn et al., 2013) and on methods for the improvement of learning settings that take a *self-improving ecologies* perspective (e.g. Ellis & Goodyear, 2010). The design anthropology approach involves close study of work practices, including tools, goals, values, skills, division of labour, *in situ*. The self-improving ecologies approach similarly tries to situate the knowledge for design and improvement *within* a system, rather than on top as some kind of external control mechanism. Thus, our primary goal is not to demonstrate the generalisability of the findings of studying collaboration in the multi-surface space. Rather, we investigate whether, how and why new tools find a place within the ecology of the studio, meshing with existing tools and resources, and with workflows, group member skills, methods, interactions etc. - helping move the whole design studio system in a more productive direction.

We do not assume that our user-designers' working methods, tool preferences, divisions of labour, or expertise are fixed. Neither do we assume that the pre-existing configuration of tools has to be maintained. We take collaborative design to be an *emergent activity* shaped in both powerful and subtle ways by the nature of the design task, its interpretation by the designers, the tools that come to hand, skills, divisions of labour, etc. Given that our overall goal is to improve design for CSCL, lessons learned in any one experiment at the design studio can have implications for the studio itself and the tools within it, and/or for the working methods used by designers, and/or for the skills that they need, and/or for the composition of design teams, role definitions, etc. In short, improving how people collaborate to design for CSCL can be achieved through enhancements to any of these components. To simplify the structure of the design activity, we use the activity-centred analytic framework of Carvalho and Goodyear (2014). This specifies the architecture of the situation in which activity unfolds in terms of the ways that activity is *physically, socially* and *epistemically* situated. As researchers aiming to support collaborative design for learning, we can manipulate each of these three loosely coupled components, while recognising that they will be reconfigured by our designers in the actuality of their work.

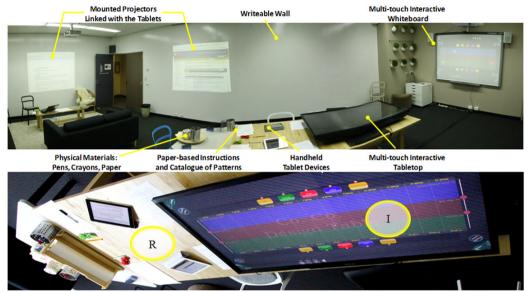
We suggest that a proper understanding of design activity depends upon close observation of how design team members use tools and other resources to accomplish their work. Following distributed but interwoven activity across heterogeneous (digital and material) networks of people, tools, artefacts is how a satisfactory description of design can be created. Our description includes some straightforward measures of the usage of the various tools available, and of the space within the studio itself. It is useful to know such things as what tools were used, for how long and for what purpose; which tools were used rarely or were left totally unused; and how people made use of the space. However, to understand the tools and space usage in the context of the activity, it is also necessary to examine the mutually-shaping relationships between the physical, social and epistemic. We illustrate some key inter-relationships in the latter part of the paper.

The Multi-touch Tabletop in the Multi-surface Design Studio

The Design Studio is a space located at The University of Sydney equipped to support teams of designers engaged in 'design for learning' activities. The Design Studio brings together a number of tools, including digital and material resources, which can be used to facilitate the work of designers. For the case study presented in this paper, we enhanced this environment with the addition and interconnectivity of multiple surface devices. We refer to this enhancement as the *Multi-surface Design Studio*. Figure 1 illustrates the physical tools available in the *Multi-surface Design Studio*. The space features: a multi-touch tabletop (enhanced with a system that can discern the identity of the user touching it, see Martinez-Maldonado et al., 2011) placed on a regular large table, an interactive whiteboard (IWB), a wall painted in whiteboard paint (writeable wall), a pair of tablet devices each connected to mounted projectors mirroring the tablet interface to each wall, and a set of materials such as paper, pens, post-its etc. Figure 2 shows the Design Studio in use and the user interface that can be displayed on either the interactive tabletop or the IWB. The prototype design software developed for this study is grounded on research-based knowledge about learning design tools that are (typically) oriented to single user-designers, but with adaptations for our intended scenarios of collaborative design use (Nicolaescu et al., 2013; Prieto et al., 2014). The principled features of the design tool are as follows:

1. **Support for simultaneous input and awareness for collaboration**. Nicolaescu et al. (2013)'s recent work suggests that collaborative design for learning, when performed online, can present awareness challenges (e.g. it is not *easy* for designers to know what the others are doing). One key feature of interactive tabletops

and IWBs is that, if the interaction mode is based on *direct touch*, it enhances the awareness and accountability of group members' actions (Evans, et al., 2014). Our prototype exploits the capabilities of the hardware to provide interface elements that can only be manipulated by direct touch (touch buttons and drag/drop gestures), which are within reach of users even if located on opposite sides of the table (Figure 2, top-left).



<u>Figure 1.</u> The Multi-surface Design Studio featuring: a multi-touch tabletop, an interactive whiteboard, writeable walls, two tablets each connected to mounted projectors, and various physical materials such as paper, pens, etc. RT: regular table. IT: interactive tabletop.

- 2. **Provision of a pattern language.** Prieto et al. (2014) reported that teachers value the provision of templates and accessible vocabulary to speed up design for learning. Design patterns can, in principle, be used to address this because they are a general reusable solution to recurring problems within a given context (Alexander, 1999). They have been widely used in architecture, manufacture and software design but are still relatively uncommon in education (Hernández-Leo et al., 2007). As with some desktop/web-based tools for learning design (Hernández Leo et al., 2005) in our prototype, a pattern language (PL) can be defined for the teachers to use pre-existent patterns as templates. For example, Figure 2 (bottom-left) shows some *instances* of the patterns (e.g. see coloured squares labelled as *Lecture, Laboratory, Group Formation, etc*) that were placed by the users on the design space by dragging and dropping *pattern templates* from a *pattern catalogue*.
- 3. **Provision of the notions of workflow and learning spaces.** Our prototype provides the use of position as a representation of time (e.g. a flipped-timeline is provided to associate learning tasks on a weekly basis, see Figure 2, bottom-left, the timeline goes from left to right in the figure). Additionally, it also provides the use of regions on the interactive space to associate learning tasks with student's learning spaces (see blue, red and green horizontal bars in Figure 1 (bottom) for the *classroom, laboratory* and *home* spaces.
- 4. **Provision of a hierarchy of tasks.** Workflows of sub-tasks can be defined as parent tasks that can have various ordered child tasks that can also contain workflows (see Figure 2, bottom-right, a user defining a task's workflow). This structure is inspired by the tree-like structure of pattern languages, the IMS-Learning Design specification (Britain, 2004), and similar desktop-based learning design tools (Prieto, et al., 2014).
- 5. **Representation of the design at different levels of detail (semester/weekly views).** The prototype can be configured to allow the design of a whole university course (e.g. courses in the host university that commonly consist of 13-14 weeks see *semester view* Figure 2, top-right). Teachers can navigate to design in detail the workflows of the tasks in the chosen week (e.g. *weekly view* Figure 2, top-right).
- 6. Allowing both guidance and flexible design paths. Prieto et al. (2014) report that teachers perceive that design for learning tools should provide scaffolding to perform quick designs. However, the ultimate decision of opting to follow the scripts or suggested templates would not only depend on the features of the tool but also on the nature of the design task and the distribution of roles and expertise among the designers.

For this, our prototype provides the option for users to create their own patterns and edit any proposed templates as required. Any number of physical keyboards can be attached easily, to allow rapid multiple-user text input.

7. Association between syllabus topics and patterns. The prototype provides a representation of syllabus topics so the learning tasks can be associated with specific topics on the syllabus. For example, Figure 2 (top-right) shows a number of labelled yellow squares aligned at the top of the IWB that can be dragged and dropped onto specific patterns to create for example the main topic(s) of a *Lecture* or a *Seminar*.



<u>Figure 2</u>. The multi-toch prototype displayed in the tabletop and IWB

Top-Left: participants face-to-face at the tabletop. Top-Right: participants working on the *semester view* at the IWB. Bottom-Left: partial snapshot of pattern instances placed on the *semester view*. Bottom-Right: participants designing the workflow of two instance patterns in the *weekly view*.

Participants and study description

We conducted a series of experiments consisting of design for learning activities in our multi-surface design studio. Four dyads (A, B, C and D), with different levels of teaching and learning design experience, and who had worked together before, participated in the study (6 females and 2 males, aged 35.7 (\pm 9) years on average). Their goal was to produce the high level design of a Unit of Study (a 13 week course) and the detailed design of at least two selected weeks (weeks 5 and 6) for an existing subject in the area of Information Technologies held at the host university. Participants followed a 30 minute tutorial that consisted of a series of steps to build a sample design, covering all possible actions that could be performed using the interactive tabletop and the IWB. Afterwards, participants were given up to one hour for the actual design activity. The average of the duration of the four collaborative sessions was 50 minutes (\pm 2). This was followed by semi-structured interviews with each dyad (20 minutes). In addition, each participant responded to a questionnaire asking about the usage (or lack of usage) of the tools and space available in the design environment.

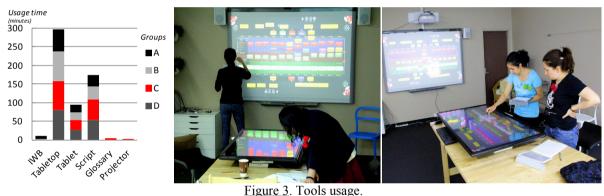
Each participant was given the following paper-based materials: the *task script* (consisting of the requirements and constraints that participants had to consider to accomplish the design tasks); and a *catalogue of learning tasks* (including some CSCL tasks and which was a simplified Pattern Language describing what each pattern was about in the context of the course). Each participant was also provided with the following digital materials displayed in a tablet: a digital copy of the *task script*; a digital copy of the *catalogue of learning tasks*; and access to the CUSP, which is an online system that provides the official description of courses in the

host university (it shows the topics, teaching rules, learning goals and a tentative schedule for specific courses). The interactive tabletop and IWB were mirrored so all the changes in either interface were immediately updated in both displays. The initial disposition of the tools and space in the design studio was the same for all the sessions (see Figure 1). Participants were told they could rearrange the furniture freely, if they needed.

To perform the analysis, we triangulated manually captured quantitative evidence about tools and space usage with the qualitative explanations from participants' interviews and questionnaires. We captured video recordings of each session and we manually recorded the time and duration of the moments when each participant interacted with a specific tool and moved to a different physical space within the design studio.

Analysis and discussion

We started the analysis of the relationship between tools usage, the group dynamics and the task, by looking at the quantitative traces of tools' usage. First, we calculated the duration of each participant's interaction with the tools available. Results showed that the most used tools were the interactive tabletop, the paper-based task script and the tablets (with an average of 27 (\pm 5), 22 (\pm 6), and 12 (\pm 1.5) minutes of usage per participant respectively). Figure 3 (left) shows the distribution among dyads in terms of usage time. It shows that other tools were scarcely used - and only by one or two dyads. These were the IWB, the paper-based glossary of patterns and the projectors mirrored with the tablets. The other non-digital tools were never used for this task; that is, the writeable wall or the paper and pencils. In previous studies, the writeable walls have been used extensively. As we explain below, tasks which involve discussions in larger teams of alternative designs in upstream/conceptual design work seem more likely to be accompanied by use of the writeable walls than do situations like the current one, where a dyad is working quickly on a more convergent, downstream design task.



Left: Tools usage time per dyad. Centre: Dyad A diving labour in different devices. Right: Dyad B working side-by-side at the tabletop

The ways in which tools were used varied widely among the dyads, as we illustrate in the following analysis. Participants often interacted with more than one tool at the same time. We measured the proportion of time spent interacting with or looking at two or more tools at a time, (e.g. interacting with the tabletop while holding a tablet or a piece of paper). On average, $61 \% (\pm 11)$ of the time participants used tools, they used them in conjunction with others. The pairs of tools that were used more often were: *the tabletop and a paper-based task script* (average of $35 \% \pm 17$ of the tools usage time by each dyad); *the tabletop and a tablet* (e.g. see Figure 3, right) ($18 \% \pm 3$); and *a tablet and a paper-based task script* ($5 \% \pm 1$). For example, one participant explained the use of multiple tools as follows: *"using the tablet and the tabletop at the same time was a really good resource in terms of looking at the schedule, teaching requirements and assessment of the subject being designed"*. It is not uncommon for computer-based design systems aimed at the solo user to involve switching between screens/windows to access different information or tools. While it is convenient to have everything in one system, for team-based design work, having persistent displays/availability of all the information/tools required is highly valuable. Shifting gaze from one surface to another is much quicker than negotiating within the team about which information or tools are needed next. Because rapid shifts of gaze are natural in human perception, this ability is taken for granted and goes unnoticed, until there is a hiatus in the flow of the work.

Regarding the use and re-use of the software-based tools, we analysed the use of patterns to achieve the task (*Relationship between tools and design task*). Most participants found it useful to work with patterns (7 of the 8 participants strongly agreed that the provision of template patterns allowed them to effectively configure the course design). One participant explained this as follows: "being able to directly drag generic tasks into the timeline helped define and refine the design". However, only one dyad accessed the paper-based glossary of

tasks to seek details about certain patterns (see Figure 3, left, glossary only briefly accessed by dyad C). This behaviour can be explained as follows: part of the task included the substitution of a number of *Face-to-face Lectures* with *Online Lectures* in a number of selected weeks of the course. Only dyad C tried to understand the pedagogical implications and the pedagogical elements that might go missing in swapping these activities. One of the group members explained that "the catalogue helped [them] understand the trade-offs of substituting online for face-to-face learning activities". This shows that this type of design thinking can emerge but it was only observed once in one of the four dyads. It suggests that further scaffolding and/or task definition may be needed to encourage better use of this tool and its associated design thinking.

Regarding the usage of the physical space of the design studio, the four dyads behaved differently and, in some cases, re-arranged the furniture provided in the Design Studio (Tools and space usage). Overall, participants mostly worked around the interactive tabletop (77.8% of the total time), and the rest of the time at the regular table (see Figure 1-RT) and the IWB (19.4% and 2.7% of the time respectively). However, the four dyads used the space in very different ways (Relationship between tools and social interactions). Figure 4 shows the heatmaps of space usage of the four dyads as captured from the video recordings. Dyads A and C worked mostly face-to-face (f2f), mostly at the interactive tabletop (IT) but also at the sides of the regular table space (RT). In fact, the use of space by dyad A reflected the division of labour they adopted. This pair worked almost separately, without maintaining awareness of the other's actions. They worked in different spaces at different times (for example, Figure 3 (centre) shows how participants in dyad A divided labour working with different shared devices). By contrast, a different strategy of space usage was followed by dyad B who worked side-byside (SxS) (e.g. see Figure 3 (right) and heatmap corresponding to dvad B in Figure 4). A third case was seen with dyad D, where participants mostly interacted at the interactive tabletop but interspersed moments of F2F and SxS work. Such positioning has implications for both the readability of the text on the table and for eye contact between the designers. Overall, different ways of working - face-to-face or side-by-side - were observed (28.9% and 29.7% of the time for F2F and SxS work among dyads).

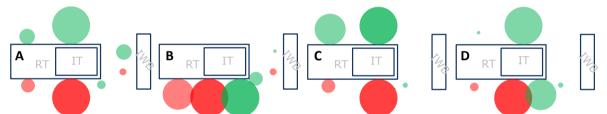


Figure 4. Heatmaps of space usage: the size of each circle represents the amount of time each group member (represented with green or red colours) spent in determined position in the design studio. RT= Regular Table; IT=Interactive tabletop; IWB=Interactive Whiteboard.

Another interesting aspect of the dyads' activity comes from an analysis of transitions between tools and spaces. The first type of transitions includes how each participant shifted attention between personal exploration of information using the tablets and interacting with the shared devices. For example, Figure 5 depicts three different versions of this, including 1) the rearrangement of the furniture to work side-by-side with each person either holding or sharing a personal device and/or working at the tabletop (e.g. dyad B in Figure 5, left); 2) participants using their personal devices at each side of the table (e.g. dyad C in Figure 5 (centre)); or 3) participants sharing their personal devices to support discussion and mutual understanding whilst working faceto-face (e.g. dyad D in Figure 5, right). Most participants commented on the usefulness of the tablets, for example: "it was easier to look at the information in the tablet, because you can hold it while interacting with the tabletop. Also the resolution of the tablet is very good for reading". Additionally, all participants reported that they used the tablets to consult the CUSP (the information about the course), and they preferred to use the paper versions of the task script and the catalogue of tasks. In this way, they preferred to give meaning to the device (e.g. correlating the physicality of the material tool with the logical resource (e.g. the tablet to consult the CUSP and the paper to access the task instructions and requirements) (Relationship between tools and task). This was explained by a dyad as follows: "It was good to have the task script on hand (paper) rather than switching in between using the tablet. It was easier to navigate through the subject resources on the tablet and have the instructions on hand so you can immediately find the information quickly when needed". In addition to capitalising on the speed with which gaze can be adjusted (mentioned above), this observation also suggests that the participants were using the location of information as a cue to (re)finding it quickly.

Two main behaviours related to transitions within the design studio space were observed: 1) holding or bringing tablets onto the tabletop surrounding, compared with 2) leaving the tablet on the regular table space

and moving to that space when needed. Figure 5 (centre) shows this contrasting behaviour in space, between the members of a dyad. For example, a participant justified her preference indicating that *"it was good to have some space on both sides of the table so we could place the tablet next to it for quickly looking or for grabbing it"*. We could not find any trend between dyads and preference of bringing the personal device to the shared space or moving to where the personal device was placed. For example, the heatmaps in Figure 4 show that mostly participants in dyads A and C and the red participant in dyad B, spent time in the regular table space.



Figure 5. Strategies of usage of personal and shared devices

Left: Dyad B working SxS with moments where participants look at the same personal device. Centre: Participants in Dyad C revising information from the personal devices. Right: Dyad D sharing a personal device whilst working face-to-face.

Finally, the transitions between the Tabletop and Whiteboard were limited. The IWB was used only by dyads A and B. Only one participant in dyad A found it useful to work on the IWB. The rest of the participants found that it was not comfortable to work on the IWB because of the length of the task (e.g. one participant indicated that *"it is more comfortable to work at the tabletop because your arms are down. You need to do more effort to interact with the IWB because you need to lift the arm"*) or because it was not easy to see the whole design while interacting with it that close. However, most participants (7 out of the 8), indicated that the interface replicated in the IWB and the tabletop helped them visualise the whole design quickly. This suggests that even though they did not interact with it, they used it to maintain some awareness of the whole design.

Conclusions and future work

We have constructed a prototype for a multi-touch tabletop as a research tool through which we can learn more about how to support CSCL designers: helping them design and redesign quickly using gestures to manipulate iconic representations of pedagogical design patterns. Rather than try to understand the use of the tabletop in isolation, we have studied its use within the larger ecology of a design studio with multiple surfaces and other tools and resources. Rather than try to make assertions about the affordances of a tool (in isolation from considerations of the skills and activities of its users) our goal is to construct an understanding of the relations between tasks, tools and people, and to discern those relations working out in the detail of what people actually do. For example, the task requested teachers to design the semester-long course without inviting them to test alternative candidate designs. Therefore, participants found it handy to use the tabletop to accomplish the task. This helps explain why they did not sketch or use other tools to brainstorm or compare, and test their ideas. This was explained by one participant as follows: "*maybe we could have used other materials if we had to try to complete a new design on paper, pass it to the digital environment using the tabletop and then discuss or present it to someone on the IWB*". On the other hand, each group used the tools in the same proportions, but had different ways to divide labour, share devices, maintain mutual awareness and complete the tasks.

Our next steps in enhancing the Multi-surface Design Studio will be informed by this and other trials, together with insights inspired by other researchers in what are sometimes very different contexts (e.g. Prieto et al., 2014). Rather than seeing others' research as a source of generally true principles from which it ought to be possible to derive specific implications for action in our own context, we can see their work as benefiting our own through a process of translation. It is in that spirit that we offer our own contributions in this paper.

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Using Differences to Make a Difference: A Study on Heterogeneity of Learning Groups

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Abstract: There is an increasing interest in student-centered teaching methods with small group learning as an important ingredient. In this paper, we present a study in which the performance of heterogeneous and homogeneous learning groups has been compared in a technology-enhanced classroom setting in the area of STEM learning. The group formation was based on learning analytics results that were considered in a semi-automatic formation process. The analytic methods used incorporated different artefact-related characteristics, but also motivational features as input. We observed that the heterogeneous groups outperformed the homogeneous ones in different ways. The results of the study are analysed using quantitative and qualitative approaches on both the individual and the group level.

Keywords: group learning, heterogeneity, inquiry-based learning, online experimentation

Introduction

There is an ongoing debate about the future of Europe being threatened by a downward trend in science education due to a lack of attraction for young people to become researchers or to work in fields of science and technology (Rocard, et al., 2007; Gago, Ziman, Caro, Constantinou, & Davies, 2004). Many initiatives point out that there is a need for more scientists and thus for fostering students' interest in science (Global Science Forum, 2006). Large scale assessments, such as PISA, show that student-centered and supportive teaching methods are needed. These aim to convey key competencies to learners by activating them, which opens new opportunities in contrast to teacher-centered approaches (Hannafin, Hill, Land, & Lee, 2014). This has been mainly underpinned by a change from teacher-centric and deductive to inquiry-based methods. Initiatives like the Go-Lab project enforce the idea of inquiry-based science education with online experimentation. Students dive into the role of researchers to investigate the big ideas of science. They receive guidance in the different steps of inquiry, e.g., through explicit phase names, scaffolds and other guidance mechanisms. Typical scenarios in Go-Lab consist of different tools and learning resources, aligned to an experiment with the Go-Lab portal serving as a general infrastructure and access point to a variety of online labs. As such, Go-Lab does neither directly support student collaboration nor classroom orchestration on the part of teachers. While collaborative online tools, especially in the context of virtual and remote experimentation, are not generally available, blended learning scenarios offer the opportunity to induce off-line collaboration in the classroom. Thus, teachers are required to set up group learning scenarios and take care of the classroom and group orchestration (Dimitriadis, Prieto, & Asensio-Pérez 2013; Roschelle, Dimitriadis, & Hoppe, 2013; Dillenbourg, 2013).

To support this kind of classroom orchestration, we employ methods from learning analytics to create student groups with specific performance characteristics. To that end, we propose a multidimensional, clustering schema that takes into consideration students' motivation towards science and students' activity style with respect to artefact-based measures in a computer-supported learning environment. With the use of the aforementioned schema, we created heterogeneous and homogeneous groups that carried out a learning activity through the Go-Lab portal. Our main objective was to compare the performance of those groups and explore whether group heterogeneity had an effect on the overall learning outcome. Usually it is expected that weak learners who are members of heterogeneous groups or medium ability learners forming homogeneous teams achieve the maximum knowledge gain (Lou, Abrami, & d'Apollonia, 2001). We argue that heterogeneous groups coordinate and create common ground faster and easier than the homogeneous groups since the different characteristics of the individuals might complement each other. This is also depicted on the quality of the activity's outcome and the knowledge gain of students.

We evaluated this hypothesis on heterogeneity in a real classroom setting where the students had to carry out an inquiry-based learning-task. In order to evaluate the knowledge gain, the students took pre- and post-knowledge tests and the outcome of the activity (concept maps, short descriptive texts and group reports) was assessed by the teacher. We used the log files of the Go-Lab portal to analyze the activity of students. In

addition, two experts were asked to observe the activity and keep notes in the form of activity transcripts in order to assess the collaborative practices of groups.

In the next sections we present a short overview of the state of the art, the experimental setting of the study and our conceptual framework. We present the analysis and evaluation of the results, a discussion on the finding of the study and we conclude with the outcome and future work.

Background and related work

Group formation is a key aspect of CSCL because it can affect the way people work together towards a common goal and eventually the learning outcome itself. Collaborative activities are expected to promote learning through common knowledge building and the social interaction among users (Stahl, Koschmann, & Suthers, 2006). However, collaboration alone does not ensure knowledge gain or successful practice (Jermann, Soller, & Muehlenbrock, 2001). Usually the task of group formation is carried out by the teacher who uses his experience on pre-defined criteria that may refer to students' social skills, gender, motivation or knowledge background (Ounnas, Davis, & Millard, 2009). This complicated process requires time and does not always lead to success.

Based on the availability of student performance data in computerized learning environments, (semi-) automatic or algorithmic approaches to group formation have been suggested. E.g., Balmaceda, Schiaffino, & Pace (2014), define group formation as a weighted constraint satisfaction problem (WCSP) depending on the characteristics of students such as personality traits, team roles, and social relationships. Also network analysis techniques have been employed for analyzing the interaction of users through a learning platform and clustering students based on their similarity (Sadeghi & Kardan, 2014). As one of the most sophisticated technical solutions so far, the GroupAL algorithm (Konert, Burlak, & Steinmetz, 2014) allows for optimizing group composition according to a variety of features, with the option of choosing between homogeneity and heterogeneity for each of these features.

The role of group homogeneity in collaborative classroom activities has been a subject of various studies. There are indications that heterogeneity of knowledge is beneficial for group performance (Webb, Nemer, & Zuniga, 2002; Kizilcec, 2013). However a certain baseline of background knowledge appears to be required for the collaboration to be beneficial (Gijlers & De Jong, 2005). In our own prior work we had also seen positive effects of diversity on the performance of learning groups (Chounta, Giemza, & Hoppe, 2014).

Experimental setting

This section covers the experimental setting of the study. First, we describe the Go-Lab platform which will be explained in line to the implemented scenario. Apart from the technical system, we explain the didactical goals and the production of learning objects by the students during this scenario. These artefacts are used for the assignment of groups and the assessment of performance characteristics.

The learning activity was split up into two phases: the first phase consists of individual student work for the initial assessment of performance characteristics. The tasks that the students had to carry out involved writing a short text to describe a simulation, and creating a concept map from different learning resources. A motivational questionnaire captured their interest and motivation in science. These characteristics served as an input for the group formation, which was used in the second phase of the study. In the second phase, the students performed an inquiry-based learning task in groups. The task objective was the online experimentation with a virtual lab of an osmotic power plant.

The outcome of the second phase was a concept map and a written report per group. The concept map should describe the parameter model of the power plant, and for the report the students had to formulate a short summary about their findings. This should include a critical reflection about the usefulness of osmotic power under different aspects, e.g. sustainability, effectiveness and dependence of the location. Four explicit assignments guided the students through the scenario and provided a scaffold for the report. However, no formal structure was given in order to promote an open-ended range of possible solutions.

Go-Lab learning environment

The Go-Lab portal is a web based learning environment for the authoring of inquiry-based learning scenarios and their implementation in classes (Govaerts, et al., 2013). The Go-Lab system follows an innovative approach to inquiry learning by providing a general infrastructure and acts as an access point to online labs. It aggregates learning resources and scaffolds, and provides guidance to learners (de Jong, Sotiriou, & Gillet, 2014). Figure 1 shows an example Inquiry Learning Space (ILS) of the environment, which has been used for this study, from the student perspective. Such learning activities consist of different inquiry phases, which are displayed as "tabs" in the navigation bar of the web environment and thus define a guided path through the inquiry process.

Learning goals

The main goal of our learning scenario is to understand the mechanism of osmotic power and how the location of an osmotic power plant influences the power generation. The learning scenario demands multidisciplinarity from the students in a way that knowledge from different subject domains such as biology, chemistry and physics is used. Also competencies from different fields such as text writing, metacognitive skills, concept mapping and inquiry skills are released during this experiment.

Critical thinking skills are demanded in the second phase of the study, where the students perform the group work task. At the beginning of the group phases, they get confronted with the "aggregated concept map" of all students (Manske, et al., 2014), which can be seen as a union of all concept maps represented as graphs. Such a structure contains useful and useless concepts and possibly wrong connections. This enforces a critical group discussion about the correctness of specific parts. In the following, students take this knowledge to create a new concept map capturing the parameter model of an osmotic power plant, while they are also confronted with some ecological factors of osmotic power and sustainability. Explicit assignments guide them through this scenario although they have to structure a final report by themselves.

Such a complex and multidisciplinary scenario, which incorporates different skills and competencies, possibly lead to a big diversity of the results. The students provide a non-standardized report as a final result, which does not allow for a simple and automated assessment. However, the benefits are in the qualitative evaluation of the reports and the group observations, which shows that it is possible to track different competencies and to have a detailed view on the students' performances.



Figure 1. The web based learning environment with the interactive osmotic power plant simulation (a), and a student using the concept mapper in this environment during the study (b).

Conceptual framework

This section covers the conceptual framework for the group formation. First, it describes the process chain for the conceptual model of the group formation, which has been applied in our experimental setting. A key aspect is the composition of a feature set to describe different performance related characteristics of learning objects and motivation. Therefore, we provide an overview about all used measurements and their backgrounds.

Group formation processing chain

We define a heterogeneous learning group as a learning group, where each member has different performance characteristics. The learners produce artifacts during an inquiry-based learning scenario as described in the experimental setting. The artefacts, particularly learning objects and the assessment of motivational scores form the dataset for the group assignment. These characteristics span a feature space, while the vector containing the scores for a single student is called feature vector, which is an element of the feature space. To use simple Euclidean distance measurements in such a vector space, the feature vectors are normalized.

In total, we capture the performance characteristics through six artefact-related and three motivational scores, leading to a nine-dimensional feature space. In terms of classroom size, the dimension is too high to produce meaningful clusters. To tackle this curse of dimensionality, we perform a feature selection to minimize the dimension to a plausible number derived from the number of students and groups.

Performance characteristics and indicators

To decide whether a group is heterogeneous or homogeneous, we capture different performance characteristics which serve as a basis for the group formation. These incorporate not only artefact-based assessment on concept maps and small texts but also motivational assessments based on the SMTSL questionnaire (Tuan, Chin, & Shieh, 2005). The following section lines out different measurements of these performance characteristics.

Concept Maps

Concept mapping (Novak, 1984) is a technique for the externalization of knowledge structures in form of semantic networks. A learner creates a concept map by connecting concepts that are considered important for a given domain by labeled relations. Since concept maps reflect the structure of domain knowledge of individual learners, these artefacts are particularly suitable as a factor additionally to knowledge tests for characterizing students (Stoddart, Abrams, Gasper, & Canaday, 2000). In order to use the concept maps of students as parameters for group formation, quantification is needed. One approach is to compare a concept map to a reference map created by a tutor or expert (Conlon, 2004; McClure, Sonak, & Suen, 1999). This requires a matching of concepts between both maps comparing labels. This can be done automatically using computer linguistic methods (Conlon, 2004; Hoppe, Engler, & Weinbrenner, 2012). However, this is not trivial and can lead to wrong matching. Since the aim of this study is to measure the impact of group formation on student performance as accurately as possible, we decided to do the matching manually in order to avoid biases introduced by automatisms. Each concept map *cm* with a set of concepts N_S and a set of relations E_S is compared to an expert map with the concepts N_E and relations E_E . Five different measures were calculated:

- Node precision: Node precision measures the fraction of concepts in a student concept map that can be matched to concepts in the expert map, $np(cm) = \frac{|N_S| \cap |N_E|}{|N_S|}$.
- Node recall: This measure indicates to what extent the concepts in the expert map are covered by the student map, $nr(cm) = \frac{|N_S| \cap |N_E|}{|N_E|}$.
- Edge precision: The fraction of concept connections in the student concept map that can be also found in the expert concept map, $ep(cm) = \frac{|E_S| \cap |E_E|}{|E_C|}$.
- Edge recall: Edge recall is defined as the fraction of edges in the expert concept map that can be found in the student concept map, $er(cm) = \frac{|E_S| \cap |E_E|}{|E_F|}$.
- HEW-measure: Hoppe, Engler & Weinbrenner (2012) introduced a quality indicator for concept maps based on the comparison of a concept map to a given ontology. The measure was obtained based on empirical observations of structural properties that correlate with expert quality judgments.

$$hew(cm) = \frac{|N_S|}{1+3|N_S \cap N_E|} + \frac{7|E_S|}{1+6|E_S \cap E_E|} + \frac{|N_S||E_S \cap E_E|}{1+6|E_S||N_S \cap N_E|}$$

We are aware that using these measures alone for a reliable assessment of the students' actual domain knowledge is limited. However, the concept map measures contribute to the creation of heterogeneous and homogeneous student groups by providing additional discriminating factors. In this sense the measures do not necessarily answer the question which students produce better concept maps but they give insights in which students produce different concept maps, and thus have different characteristics.

Text writing

While text analytics and approaches of text mining still have huge deficits especially for short texts written by students in STEM fields (Leeman-Munk, Wiebe, & Lester, 2014), we used a non-automatic measurement for the text quality characteristics. A teacher creates a model solution and scores the texts in respect to the model. This led to plausible scores without the possible downsides of text mining on short texts in sciences.

Motivation

As motivation is one of the key ingredients for successful group work, we incorporated three measures for motivation towards science. The SMTSL questionnaire has been used in a shortened version to assess scores in

three different categories of motivation: (a) Self efficacy, (b) Science Learning Value, and (c) Learning Environment Stimulation.

Evaluation

In this study we aim to explore how group formation affects the practice of students and their performance in collaborative learning activities. To that end, we formed homogeneous and heterogeneous student groups using a multidimensional clustering schema based on artefact-related characteristics and motivational scores, as described above. In order to evaluate the practice of students we used both a qualitative (expert observations) and a quantitative approach (learning analytics). In order to assess the students' performance, we carried out pre-knowledge and post-knowledge tests. In the following paragraphs, we present the results of the analysis and discuss the findings of the study.

Quantitative analysis

The interaction of students with the learning platform was recorded in log files. We used the log files to extract metrics of students' activity and further explore any possible relation with qualitative characteristics and the overall knowledge gain. The scores of the knowledge tests ranged from 0 to 35 points and we used them to assess the learning outcome. Additionally we defined the activity metrics portrayed in Table 1 in order to evaluate the interaction of students with the learning platform.

Table 1: Activit	y metrics	extracted	from	user log files

Metrics of students activity on the concept map							
	name	description					
learning platform related activity	#actions	number of actions					
	duration (min)	overall duration					
	avgtimegap (sec)	time gap between consecutive actions on average					
concept map related activity	#concepts	number of created concepts					
	#relations	number f drawn relations					
	#add	number of added objects					
	#up date	number of updates					
	#delete	number of deleted objects					

In Table 2, we present the results of the knowledge tests per group. According to the results, the heterogeneous groups appeared to have a higher knowledge gain than the homogeneous groups. The heterogeneous groups improve their score in the post knowledge test on an average of 33% while the homogeneous groups improved their score about 20%. In the current study, group homogeneity does not ensure that the members of a group share similar knowledge background. For example, the members of group G2 that is considered heterogeneous, scored similarly in the pre-knowledge test (pre-STDEV = 0.5). On the other hand, the pre-test scores of the members of group G6 that is considered homogeneous, portray a big deviation (pre-STDEV = 6.50).

Table 2: Results of the pre and post knowledge tests for heterogeneous and homogeneous groups

	Heterogeneous groups			Homogeneous groups				
	G1	G2	G3	avg(G1_3)	G4	G5	G6	avg(G4_6)
Pre-test score	16.00	15.33	15.50	15.61	12.67	18.67	12.50	14.61
Pre-STDEV	1.41	4.78	0.50	2.23	2.05	1.70	6.50	3.42
Post-test score	23.33	23.00	23.50	23.28	16.17	24.00	15.00	18.39
Post-STDEV	3.40	4.90	0.50	2.93	3.32	1.47	5.00	3.26
Avg gain	7.33	7.67	8.00	7.67	3.50	5.33	2.50	3.78

The results of the knowledge tests were studied in comparison with the metrics of user activity. However, we were not able to draw any plausible conclusion for possible relations. The groups' activity, as portrayed in the log files of the learning platform, was similar for all groups (Table 3). A common hypothesis made in similar studies is that collaboration quality and knowledge gain are usually depicted in activity metrics, i.e. intense activity will lead to a solution of better quality (Kahrimanis, Chounta, & Avouris, 2010). This hypothesis however was not confirmed in this study.

Table 3: Group activity metrics for heterogeneous and homogeneous groups

	Heteroge	eneous gr	oups	Homogeneous groups			
	G1	G2	G3	G4	G5	G6	
#actions	30	57	56	38	56	60	
duration (min)	23.82	48.42	21.67	16.77	25.67	29.75	
avgtimegap (sec)	49.28	52.94	23.64	27.19	28.00	30.25	
#concepts	13.00	28.00	24.00	19.00	23.00	29.00	
#relations	10.00	25.00	28.00	12.00	23.00	27.00	
#add	13.00	24.00	24.00	17.00	24.00	26.00	
#up date	12.00	24.00	28.00	14.00	23.00	27.00	
#delete	0.00	6.00	1.00	2.00	2.00	4.00	

Qualitative analysis

During the group phase of the study, the users had to create a concept map based on what they learned and to write a report. A teacher rated both the concept maps and the reports of the groups. This way, we wanted to ensure the findings from the pre and post knowledge tests. The concept maps were rated in a [0, 8] range and the reports were rated within the range [0, 12]. The ratings of the teachers for the concept maps and the work reports are presented in Table 4. The results of the ratings with respect to group homogeneity confirm the findings of the knowledge tests. The heterogeneous groups are higher graded than the homogeneous ones for both the concept maps (21.4%) and the final work reports (29.6%).

Table 4: Teacher ratings of the concept maps and work reports per group

	Heterogeneous groups					Homogeneous groups			
	G1	G2	G3	$avg(G1_3)$	G4	G5	G6	avg(G4_6)	
Concept Map Scores	4	7	3	4.67	1	2	2	1.67	
Report Scores	10	11	6	9.00	2	6	4	4.00	

The practice of students was recorded in transcripts by two experts who attended the study. In addition, a third expert took general notes of the activity (e.g. notes about the timeline and events that might affect the activity). From the analysis of the transcripts, we identified three main group types: (a) Type A: One student operates the computer, the rest comment or guide him verbally, (b) Type B: Group members change roles frequently regarding typing and directing and (c) Type C: One student is actively involved in the task, the others watch silently or do not do pay attention.

Two out of three heterogeneous groups (Gl and G3) were identified as of type B. The experts stated that even though they started out shyly, they managed to create a common ground and share responsibilities and tasks. They were enthusiastic about the activity until the end and seemed to enjoy it. For the group G3 in particular, the experts noted that they did not communicated openly (talking or arguing, etc.) and sometimes they were hesitant to act. Towards the end of the activity they did not interact between them but they carried on working separately even though they shared the use of the computer. This group score the highest score in the post-knowledge test and the maximum knowledge gain. The third heterogeneous group (G2) was identified as type C. According to the experts' observations, one particular student took over the activity but continuously tried to involve the other members by giving detailed explanations on every step of the process.

For the homogeneous groups, two were identified as type A (G4 and G5). According to the transcripts, the students of both groups were hesitant in the beginning. For group G4, it took them considerable effort to start communicating and one student took action in order to move forward with the activity. In group G5 one student appeared to be more aggressive and active and dominated the activity from the start. Gradually all students began to participate within their groups. For group G4, however, it was too late to catch up while group G5 lost motivation towards the end. We think that the time the individuals needed in order to coordinate with the rest of the group members was critical and in the end this is depicted in the learning outcome. The third homogeneous group (G6) was identified by experts as type C. According to the experts' observations, one group member carried out the whole task while the other one was silently watching. Despite the fact that the active student tried to involve the other member in the activity, there was no collaboration or argumentation. Group G6 had the lowest score on average in the post-knowledge tests and also the minimum knowledge gain.

It is worth mentioning that the groups which were identified as type C had the maximum group deviation in the pre-knowledge tests (Pre-STDEV, Table 2). This practically means that in both groups there

was a "strong" student who eventually dominated the activity. However, in the case of the heterogeneous group the knowledge gain on group average was higher than in the case of the homogeneous group.

Discussion

In this paper, we discuss the effect of group formation strategies on students' collaboration and the learning outcome. Analysis showed that the heterogeneous groups increased their performance and appeared to have a higher knowledge gain than the homogeneous groups. On an individual level, the students who were members of heterogeneous groups had a knowledge gain of 33% on average while the students who formed homogeneous groups improved their individual performance for about 20% with respect to the pre-tests. This finding was also confirmed by the teacher ratings of the concept maps and the group reports. Heterogeneous groups were graded higher than homogeneous groups for the quality of the concept maps they provided through the learning platform and for the quality of the written reports.

In order to assess the group activity with respect to collaboration quality, we used activity transcripts where experts recorded their observations. The experts stated that the students of heterogeneous groups adjusted their practice easier than the students of homogeneous groups. They undertook roles and responsibilities faster and without conflicts. Even in the case when they didn't seem to communicate on a satisfactory level, they managed to carry out the task efficiently. On the other hand, homogeneous groups needed more time in order to create a common ground and to collaborate effectively. In some cases this was proven critical since some of the students lost interest and others were unable to carry out the task in time.

Additionally, we used the log files of the learning platform to define metrics of user activity. To that end, we followed popular approaches where activity metrics were introduced as indicators of good collaboration quality or efficient group practice (Kahrimanis, Chounta, & Avouris, 2010). However, we were not able to prove any relation between activity metrics and the learning outcome. The group practice was similar for most cases with respect to activity metrics and group homogeneity. We should however keep in mind that due to the study setup one could argue that the activity metrics do not reflect group work or collaborative practice and therefore we should not expect a correlation with the overall group picture.

Conclusion

To tackle the issue of how to engage students in sciences and capture their interest, we propose the usage of rich inquiry-based learning scenarios, as demonstrated in the Go-Lab project. Incorporate online learning with classroom presence leads to blended learning scenarios. This gives the opportunity to take the collaborative parts of the learning into the classroom, with all its benefits and challenges for the teacher. We propose a way to support the group orchestration through the application of learning analytics, particularly the analysis of learning objects and assessed motivation. Finally, we conducted an experiment and applied methods of sequence and log file analysis to validate our hypotheses through multi-level analysis.

The analysis of our results indicated that heterogeneous groups outperform the homogeneous ones and achieve higher knowledge gain. Thus, there is no benefit of choosing homogeneous groups in terms of performance. Even though when having a group with only good performing students, they still do not perform significantly better than the heterogeneous groups, but they don't compensate the weaker performance in the other homogeneous groups with weaker characteristics. For the class average, heterogeneous groups are better in sum, while it also covers basic principles of fairness, which is reflected by a lower diversity between the groups' performances. Fairness is both a principle that can influence the motivation of students in a further way but also underpins pedagogical decisions and thus is one of the important steps towards successful internal differentiation of learner groups. The results of this study cannot be generalized due to the small number of participants; however they can serve as indications for group formation. In future work, we aim to conduct large-scale studies in order to confirm the outcome in a statistically significant way.

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Assessment and Collaborative Inquiry: A Review of Assessment-Based Interventions in Technology-Enhanced K-14 Education

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Abstract: We provide a conceptual review of the research on assessment in technologyenhanced collaborative inquiry in K-14 education, published between 1994 and 2013. The 57 studies that satisfied our search criteria were coded using a framework that considered the nature of the assessment intervention, the purposes of the assessment intervention, and the role of technology in student learning. This allowed us to identify four types of assessment interventions. The findings indicated that only interventions in the immersion orientation seemed to help students *learn how to learn*. Such assessment practices enabled students to learn actively and to learn both disciplinary substance and metacognitive/regulative skills. However, relatively few studies clearly integrated assessment and learning. The main contributions of this study are the coding framework and the four patterns of assessment interventions. Together, they provide a new way of thinking about the design of practice. The review provides guidance for the shift of assessment practice to scaffold learning of this field.

Keywords: assessment, learning, technology, collaborative inquiry, scaffolding

Introduction

In the last few decades, collaborative inquiry has emerged as an important research area in computer-supported collaborative learning (Stahl, 2002). Despite substantial development in learning theories, assessment, and the use of educational technology, it remains unclear whether assessment practices have changed in classrooms where educational technology is used to support collaborative inquiry. Theoretical developments suggest that assessment should be used to both measure students' achievements and to scaffold future learning; furthermore, an increased emphasis on collaboration in learning requires assessment procedures that consider both individual and shared achievements (van Aalst, 2013). The role of students in assessment also continues to be neglected. Educational technologies often store large amounts of information about the learning process, which could be used to enhance learning. Thus, assessments that involve educational technology are of particular interest. The use of assessment data to improve learning is gaining some momentum in the policy discourse on education (Datnow & Park, 2014).

Most reviews of the assessment literature have focused on higher education; relatively few have focused on assessment in K-14 education. At the same time, there is a lack of systematic empirical evidence on how assessment practices can be designed to guide learning. This study reviews the latest developments in assessment in technology-enhanced K-14 education, with a view to articulating an agenda for further research and development. The question that drove the review is How are assessment interventions designed to scaffold students' learning? In this study, assessment refers to any evaluative practice that is "part of everyday practice by students, teachers and peers that seeks, reflects upon and responds to information from dialogue, demonstration and observation in ways that enhance ongoing learning" (cited in Klenowski, 2009, p. 268). The definition is used to distinguish this type of assessment practice from others that focus on measuring students' academic achievement through standard tests, or final exams.

In the following section, we present the method and procedures used in the literature review, followed by a detailed analysis of the reviewed studies. We then discuss the key issues and consider the implications of this study for assessment practice and further research.

Methods

Criteria for inclusion

The following five criteria were established to select studies for inclusion in the analysis. (1) *Empirical and peer-reviewed journal articles published in English between 1994 and 2013*. Non-empirical literature, review articles, opinion articles, conference papers, dissertations, book chapters, and books were selected in the initial stages of the literature search to serve as sources of relevant research. However, they were not included in the

final analysis. (2) *Studies conducted in K-14 education, excluding medical education.* We chose K-14 rather than K-12 education because there is considerable variation in when postsecondary education starts. For example, the content of college courses can be similar to that in the final year of high school and many high schools offer university-level courses in the final year. (3) *Studies that focused on educational and formative assessment practices.* Studies that focused on assessment practices that facilitate and transform learning, rather than those used for measurement or educational evaluation purposes were included.(4) *Studies that used technology to enhance student learning and assessment activities.* We only included studies that involved technology in some part of the learning contexts to increase learners' engagement, creating opportunities for collaboration, reflection, and self-regulation, and providing advice before and during the assessment activities. (5) *Studies that provided a clear description of the methodological characteristics necessary for our analysis.* We only included articles with a clear description of the following variables: *the definition of assessment, data source, sample sizes, treatment, research design, and outcome.* If the outcomes were not sufficiently well defined or measured for us to assess the accuracy of the results, then the study was excluded.

Search procedure

The literature search was conducted in a three-step process. First, an exhaustive search of peer-reviewed journals was conducted using the EBSCOhost, ERIC, and PsycINFO databases. The following combinations of descriptors were used: formative assessment, self-assessment, peer-assessment, embedded and transformative assessment, and reflective assessment. This search retrieved 123 studies based on the examination of the titles. Second, to locate other relevant studies, an exhaustive search of the major journals that publish research in the learning sciences, specialize in assessment in education, and specialize in reviews of educational research studies was conducted. The literature search was conducted in learning sciences journals because this is an emerging interdisciplinary field that aims to improve formal and informal education by designing complex learning environments and studying how learning is accomplished in them.

These two steps retrieved 250 studies. After applying the selection criteria to the titles, abstracts, and research designs of these 250 studies, 46 studies were retained. This significant reduction was due to the limited number of studies conducted in K-14 educational contexts and the extended use of the term *formative assessment* to refer to *any* kind of assessment adopted in the learning process. However, in most of these studies, assessment was only used summatively and students did not act as active agents who generated feedback, monitored their learning, and made further plans based on feedback/information to further transform their learning. In the third step of the literature search, ancestral and decadency searches were conducted by reviewing the references in the previously identified 46 articles and in relevant opinion and review articles to identify additional relevant research studies. An additional 11 studies that satisfied the inclusion criteria were identified at this stage, increasing the number of studies to 57.

Emergence of a coding framework

To determine how the design of assessment interventions can encourage guide (scaffold) learning and how scaffolds are used to make assessment practices work in a productive way, it was necessary to consider the detailed documentation of each study and to analyze the core characteristics of the assessments. A three-dimensional framework was developed to capture the core characteristics and features of such practices. By core characteristics we mean the goal/purpose of an intervention, the processes and activities planned to realize the goal, the role of technology in the process and activities, and the evidence collected to demonstrate success in achieving the goal. The three-dimensional framework was determined on the basis of a preliminary analysis of an initial sample of the articles, followed by further refinement after the preliminary analysis was presented to our research team.

The constant comparative method (Strauss, 1987; Strauss & Corbin, 1998) was used to create this coding framework. This is an iterative coding approach (Bogdan & Biklen, 1998; Miles & Huberman, 1994) that usually involves examining each individual article, forming various categories, comparing categories, and achieving category saturation. On the basis of this iterative process, three dimensions with subcategories were identified. The three dimensions were presented to our research team, and researchers with experience of coding provided feedback on the conceptual framework and the coding procedures. The conceptual framework for the review was reconceptualized and reframed accordingly, and the coding process went through a second iterative process. Finally, the following three dimensions with subcategories were identified: the nature of the assessment intervention, the purposes of the assessment intervention, and the role of technology in student learning (see Table 1). Each study received only one code in each of the three dimensions.

Table 1: Coding categories and descriptions

Nature of assessment intervention	Description
Culminating activity	One-time assessment activities that are connected or disconnected from curriculum or activities; the assessment requires student application of pre- determined criteria or construction of assessment criteria to evaluate their own or other's work after initial content instruction or after completing the whole or part of a scientific inquiry.
Continuous assessment	Assessment activities in which students improve their work based on continuous feedback or information from teachers, peers, technologies, or themselves. The feedback or information aims to narrow/close the gap between the present state and the desired goal (Bell & Cowie, 2001a).
Dynamic assessment	 Activities in which players (e.g., researcher and student) interact in a guided learning situation in which the more experienced participant selects, focuses, and provides feedback on an environmental experience in such a way as to create appropriate learning sets (Magnusson et al., 1997). Participants' knowledge is assessed in the context of mediated learning situations that attempt to foster conceptual change in a specific domain.
Intrinsic component of learning	Assessment activities are incorporated into a holistic learning and teaching framework, in which learners perform the assessment throughout the inquiry and learning process.
Purpose	
Academic performance	Assessment is used to facilitate content retention and learning, with content as a body of correct information.
Disciplinary substance	Assessment is used to assess and enhance students' domain-specific ideas, thinking, and reasoning.
Learning how to learn	Assessment is used to scaffold students to develop self-regulative and metacognitive skills such as planning, monitoring, evaluation, and reflection.
The role of technology	
Providing/facilitating assessment and feedback	Offering regular and formative online tests, providing rapid and detailed feedback/prompts; supporting teachers/tutors to write assessments and feedback in a timely manner.
Making learning/assessment activities/tasks authentic	Providing an authentic context in which learning and assessment activities are performed; creating an assessment that is authentic to the concepts or competence being assessed or tested.
Creating opportunities/spaces for group work	Creating opportunities/space to facilitate collaboration and peer assessment; encouraging learners to stimulate and scaffold each other's learning; a virtual learning community to enable learners to collaborate with each other.
Providing information/ opportunities to encourage learner reflection/self-regulation	Providing learners with information or opportunities that scaffold them to regulate their learning process toward an assessment goal, such as decoding the feedback message, internalising it, and evaluating and modifying their work with it; offering information or opportunities to help students develop reflective skills.

Results

Our review of the 57 studies indicated that assessment interventions were implemented in a variety of ways to support collaborative inquiry in technology-enhanced K-14 classrooms. The interventions ranged from those that used assessment as an added element of learning and aimed to improve academic performance by providing student feedback to those that emphasized assessment as an integral part of learning that helped students learn how to learn. Within this variation, four orientations were evident: interventions as an instrument to improve students' academic performance (outcome), interventions to facilitate collaboration in learning processes (collaboration), interventions as an instrument to help students learn disciplinary substance (disciplinary substance), and interventions that immerse students in the inquiry process to help them learn how to learn (immersion) (See Appendix).

Interventions to improve academic performance: Outcome-oriented

In eight studies (14%), interventions were used to enhance students' academic achievement. These interventions seemed to be guided by a tacit presumption that learning content consisted of a body of correct information, centered on terminology and measureable skills that was selected in advance as a learning objective. The interventions were used to narrow or close the gap between students' present performance and some targeted outcome. Interventions in this orientation facilitated assessment activities through scaffolds such as *assessment rubric, direct instruction, structuring the tasks, prompts, and assessment strategies.* For example, Hume and Coll (2009) reported on students' use of rubric-referenced assessment to rate peers' work. These assessment rubrics, which had specific evaluating dimensions (e.g., format, timing, and reporting requirements) scaffolded students to quantitatively rate peers' work. Similar directional scaffolds were provided by a Web-based assessment system (Wang, Wang, & Huang, 2006; Wang, 2007).

Interventions often provided *explicit instruction or* working examples to foster students' active involvement in assessment activities. In the study by Fontana and Fernandes (1994), direct instruction coupled with task structuring was used to facilitate students' assessment activities. For instance, in regular self-assessment activities, students were instructed to understand both the learning objectives and the assessment criteria, and were given opportunities to choose and use the learning tasks that provided them the scope to evaluate their learning outcomes. In Ozogul, Olina, and Sullivan (2006), working examples combined with assessment criteria were used to scaffold students' lesson plan writing.

Facilitating collaboration in assessment activities: Collaboration

The second orientation, collaboration, helped students to develop collaborative skills or to facilitate productive collaboration in assessment activities (eight studies, 14%). The intention was markedly different from the previous orientation's, and could be broadly described as focusing on collaboration rather than academic performance. One strategy used to scaffold student collaboration in peer assessment was *reducing problems such as carelessness and favoritism*. For instance, Lai and Lan (2006) described the "negotiated agreement" approach and the use of computer agents to minimize subjective judgments and unfair assessments. Kao (2013) reported the use of peer assessment with positive interdependence (PAPI) to engage students in productive collaboration. PAPI, which integrates the two approaches of positive interdependence and personal accountability into the assessment process, was designed to reduce or eliminate carelessness and favoritism in peer assessment and to improve the overall quality of peer reviews.

Increasing peer interaction was another strategy used to support collaboration. Kwok and Ma (1999) applied an approach involving collaborative assessment in which GSS supported students and teachers' collaborative construction of evaluating schemes. Lin and Lai (2013) used social network awareness (SNA) to promote the opportunities of peer interaction and collaboration. The social network awareness, visualized in the social network awareness for a formative assessments system (SNAFA) system, enabled students to seek peer online help and supported information sharing and co-construction of knowledge by keeping students aware of peers' social and knowledge context. Roschelle et al. (2010) reported the use of group-level feedback coupled with worked examples of productive collaboration to promote students' collaborative behavior, such as discussion, explanation, cooperative negotiation, and group-level evaluation and feedback, scaffolded by a software program.

Interventions to facilitate disciplinary substance learning: Disciplinary substance

Twenty-three (40%) interventions adopted the disciplinary substance orientation, which seemed to be guided by the notion that assessment involves genuine engagement with disciplinary ideas, thinking, and reasoning. These interventions engaged students in progressively constructing scientific theories (explanations) and/or developing disciplinary thinking and reasoning skills in investigative and collaborative contexts. They facilitated students' engagement with ideas through scaffolds such as assessment rubric/assessment worksheets, prompts, creation of inquiry contexts/tasks, and structuring learning tasks/activity.

Interventions that used scaffolds such as assessment rubrics, assessment worksheets, and assessment instruments were used to enhance students' development of disciplinary ideas, thinking, and reasoning. For example, Lin, Hong, and Lee (2011) described the use of worked examples of scientific explanations, and a reflective peer assessment instrument containing six open-ended questions with competing theories, to support students' collaborative argumentation and conceptual understanding. Similar interventions were reported in Li, Liu, and Steckelberg (2010) and Toth, Suthers, and Lesgold (2002). Creating inquiry context or tasks was another strategy used to support student learning. For example, Chin and Teou (2009) used concept cartoons to create an inquiry situation to encourage students to discuss, articulate, question, evaluate, and reflect on their own and their peers' ideas, and to elicit their ideas, including misconceptions and argumentation, about the

scientific concepts. Etkina et al. (2010) designed conceptual design tasks, supported by the Investigative Science Learning Environment, which integrated cognitive apprenticeship and ongoing assessment supplemented by reflection to help students develop their scientific abilities. Students used assessment rubrics to self-assess their inquiry process and guide their experimental design and report writing.

Provision of *working examples and prompts* was a third strategy. For example, Woo, Chu, and Li (2013) used online writing prompts to guide students' group writing. Treagust, Jacobowitz, Gallagher, and Parker (2001) engaged students in learning by asking them to respond to various questions during the activities. *Structuring learning activities or tasks* was a fourth strategy, used to direct students' attention to disciplinary substance. For instance, in Taasoobshirazi, Zuiker, Anderson, and Hickey (2006) and Anderson, Zuiker, Taasoobshirazi, and Hickey (2007), a four-step review routine was used to foster students' understanding of astronomy and to develop their reasoning skills. The four-step review routine asked students to explain and compare each answer, reach an initial consensus, review the explanation of the answer, and then confirm the group's understanding. Students were encouraged to provide claims and use data to justify them.

Immersion in inquiry process to help students learn how to learn: Immersion

The final type of orientation (15 studies, 26%) used assessment to help students learn how to learn by improving their metacognitive/self-regulative awareness and their abilities to monitor, evaluate, reflect, and re-plan. In this orientation, assessment interventions were an intrinsic component of students' inquiries; assessment was embedded in the inquiry process and further transformed their learning. Interventions in this orientation facilitated assessment activities using scaffolds such as assessment rubrics/principles/forms, models/examples, and prompts.

The interventions that used assessment rubrics, assessment principles, and assessment forms were designed to help students learn how to learn. In a series of studies, Chang (2008) and Chang and Tseng (2009, 2011) reported on the use of assessment forms embedded in a Web-portfolio system to foster students' metacognitive activities, such as self-/peer-assessment and reflection. The Web-based portfolio assessment system itself provided students with a metacognitive model that fostered their engagement in a series of metacognitive activities, such as setting learning goals, writing reflections, creating their own portfolios, viewing and emulating peer projects, conducting self-/peer assessment, providing feedback, and continuously improving their work. In another series of studies, Lee, Chan, and van Aalst (2006) and van Aalst and Chan (2007) described the use of a set of principles combined with e-portfolios to help students learn how to learn. These principles worked both as a conceptual framework to scaffold students' inquiry, and as assessment criteria to guide their reflections on the quality of their work in preparing and reflecting on the e-portfolios. Through assessment, the students monitored, evaluated, and re-planned their inquiry processes and products.

The provision of *metacognitive models/working examples* was another strategy used to help students learn how to learn. For example, Kostons, van Gog, and Paas (2012) used modeling examples to help students acquire self-assessment and task selection skills and further used the obtained skills to support students' self-regulated learning. White and Frederiksen (1998) used a metacognitive model of research (the Inquiry Cycle) and a metacognitive process (reflective assessment) in a computer-supported curriculum to engage middle school students in learning about and reflecting on their inquiry process as they constructed and applied increasingly complex causal models of force and motion. *Prompts* were a third strategy for engaging students in learning how to learn. For instance, Wang (2011) described the use of five strategies (adding answer notes, stating confidence, reading peer answer notes, recommending peer answer notes, and querying peers' recommendations on personal answer notes) provided by a peer assessment system to help students foster self-regulated awareness and skills.

The assessment orientations were derived from the nature of the interventions. The outcome orientation emphasized the improvement of students' academic performance, as the assessment interventions were used as instruments to narrow or close the gap between actual results and expected goals. The collaboration orientation tended to foster productive collaboration in assessment activities and to help students develop collaborative capacity. The disciplinary substance orientation engaged students in the development of disciplinary substance in collaborative environments that mediated their learning. The immersion orientation included assessment activities that facilitated students' development of metacognitive/self-regulative awareness and skills for learning how to learn such as monitoring, evaluation, reflection, and re-planning. Three studies (5%) could not clearly be grouped into any of the four orientations.

Discussion and conclusions

This review explored how assessment practices in K-14 education are currently used to scaffold students' learning, with a view to articulating an agenda for research and development. We reviewed technology-

enhanced, cognitively oriented research on assessment in K-14 classrooms published between 1994 and 2013. The selected articles were coded using a three-dimensional coding framework that considered the nature of the assessment intervention, the purposes of the assessment intervention, and the role of technology in student learning. This framework was developed to capture the characteristics of the assessment interventions, and to provide data for further analysis of how assessment interventions scaffolded student learning and which strategies made assessment activities work to scaffold learning.

Documenting the core characteristics of each intervention in this way clarified how the outcome of each study was determined by its overall design rather than by a single core characteristic. The documented characteristics also revealed how scaffolds, strategies, and methods were used to make a particular assessment practice work in a productive way in each study. This method differed from that of previous reviews (e.g., Black and William, 1998), which reported either the results or the effect size of the assessment interventions, with little description of the assessment processes or assessment activities that the students were involved in. Furthermore, most of the previous reviews focused on higher education, whereas this review focused on the K-14 educational context, which has received little attention. In addition, previous reviews of the literature have generally focused on interventions in which teachers played a central role in initiating assessment tasks and providing feedback. However, this review analyzed a body of research dealing with assessment practices in which students, with technological support, assessed (through peer- or self-assessment), managed, evaluated, monitored, and reflected on their own collaborative inquiry.

The review found that assessment interventions ranged from those that used assessment to provide feedback that could improve academic performance to those that helped students learn how to learn using an inquiry process focused on learning disciplinary substance; others used technology to provide information or feedback and some integrated technology into the inquiry process. All of the interventions to some extent scaffolded students' learning. However, only interventions in the immersion orientation seemed to fully help students to *learn how to learn*. This approach seems the most promising for facilitating students' agency in the inquiry process and to further transform their learning. The review also found that requiring students to monitor, evaluate, and reflect on their progress in light of criteria and principles related to learning goals had positive effects on their ability to learn actively, and to learn both disciplinary substance and metacognitive/regulative skills. However, not many assessment interventions engaged students in metacognitive activities.

The review should facilitate further research on the use of assessment to scaffold students' learning. The findings provide evidence suggesting that some promising features (e.g., students' engagement in metacognitive activities in assessment practice) contribute to both students' disciplinary substance learning and learning how to learn. However, the limited assessment designs and findings may not be sufficient for researchers and teachers to design strong and successful assessment activities to scaffold students' learning. We hope that more educational researchers will work toward this goal.

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* References marked with an asterisk indicate studies included in the review (Not a full list of all of the reviewed studies).

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	intervention	Lupuasis		ormano
Outcome orientated	Culminating activity	Academic performance	Providing/facilitating assessment and feedback	-
(n = 8, 14%)	Culminating activity	Academic performance	Creating opportunities/spaces for group work	1
	Culminating activity	Academic performance	N/A	1
	Continuous assessment	Academic performance	Providing/facilitating assessment and feedback	ю
	Continuous assessment	Academic performance	Providing opportunities to encourage reflections/self-regulation	1
	Intrinsic component of learning	Academic performance	N/A	1
Collaboration	Culminating activity	Collaboration	Creating opportunities/spaces for group work	1
(n = 8, 14%)	Culminating activity	Collaboration	N/A	1
	Continuous assessment	Collaboration	Providing/facilitating assessment and feedback	1
	Continuous assessment	Collaboration	Creating opportunities/spaces for group work	2
	Intrinsic component of learning	Collaboration	Providing/facilitating assessment and feedback	1
	Intrinsic component of learning	Collaboration	Creating opportunities/spaces for group work	1
	Intrinsic component of learning	Collaboration	Providing opportunities to encourage reflections/self-regulation	1
Disciplinary	Culminating activity	Disciplinary substance	N/A	1
substance	Continuous assessment	Disciplinary substance	Creating opportunities/spaces for group work	9
(n = 23, 40%)	Dynamic assessment	Disciplinary substance	Providing/facilitating assessment and feedback	1
	Dynamic assessment	Disciplinary substance	Making learning/assessment activities/tasks authentic	7
	Dynamic assessment	Disciplinary substance	N/A	1
	Intrinsic component of learning	Disciplinary substance	Providing/facilitating assessment and feedback	4
	Intrinsic component of learning	Disciplinary substance	Making learning/assessment activities/tasks authentic	4
	Intrinsic component of learning	Disciplinary substance	Creating opportunities/spaces for group work	1
	Intrinsic component of learning	Disciplinary substance	Mix	1
	Intrinsic component of learning	Disciplinary substance	N/A	2
Immersion	Culminating activity	Learning how to learn	Providing opportunities to encourage reflections/self-regulation	2
(n = 15, 26%)	Continuous assessment	Learning how to learn	Creating opportunities/spaces for group work	1
	Intrinsic component of learning	Learning how to learn	Making learning/assessment activities/tasks authentic	1
	Intrinsic component of learning	Learning how to learn	Creating opportunities/spaces for group work	ю
	Intrinsic component of learning	Learning how to learn	Providing opportunities to encourage reflections/self-regulation	4
	Intrinsic component of learning	Learning how to learn	Mix	4
Does not fit into the	Intrinsic component of learning	N/A	Making learning/assessment activities/tasks authentic	1
orientations	Culminating activity	N/A	N/A	1
(n = 3, 6%)	Continuous assessment	N/A	N/A	1 57

Appendix: Patterns of assessment interventions in technology-enhanced K-14 education

The Role of Time, Engagement, and Self-Perceived Leadership on Peer-Nominated Emergent Leadership in Small Group Online Collaborative Learning

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Abstract: The study investigated the nature of leadership emergence in small group online collaborative activities. The study tested the effects of time, engagement, and self-perceived leadership on peer-nominated leadership. Results indicated that emergent leadership perceived by peers in a group not only required individuals' active engagement and self-perception of their leadership role, but also required the leadership to be developed over time. High levels of perceived task leadership and active engagement would lead to more likelihood for individuals to be perceived by peers as emergent leaders in a group. Qualitative analysis revealed that quality of posts, active facilitation, quantity and diversity of posts, significant contribution, initiation of interaction, and motivating promotion were primary characteristics of emergent leaders.

Keywords: emergent leadership, small group online learning, collaborative learning

Introduction

Leadership roles often emerge in group-learning activities, where students commonly take different social roles in the process of completing collaboration tasks (French & Stright, 1991). The emergence of leadership is a social process during which individuals with no formal authority become leaders (Neubert & Taggar, 2004). Emergent leadership plays a crucial role of the success of small group collaborative learning activities. Members of the group can lead different aspects of the collaborative learning process. For example, one member can facilitate communications among team members; another person may mediate to resolve conflicts. Gressick and Derry (2010) found that leadership did emerge and was distributed among group members in online collaborative learning activities. Li and colleagues (2007) found emergent leaders led in various means such as turn management, argument development, planning and organization, topic control, and acknowledgement. Particularly in online learning? Why do some individuals become emergent leadership while others do not? What are the determining factors for individuals to become emergent leaders? What is the dynamic process of leadership formation in small group learning?" remain unanswered. There has been limited research on what the nature of leadership emergene is in authentic classroom group learning activities (Edwards, 1994; Gressick & Derry, 2010; Yamaguchi, 2001).

Traditional leadership research has often conceptualized emergent leadership as outward characteristics and behaviors that can influence the entire group (e.g. Yukl, 1989; Carte, Chidambaram, & Becker, 2006). Leaders may regulate team members' performance and provide rewards, caring, motivation, and intellectual stimulation to others (Avolio, 1999; Bass, 1998; Gibson & Vermeulen, 2003). Leaders can promote group cohesiveness by managing the task or fostering a positive group environment (Huang, et al., 2010). They also monitor task progressions, direct group interactions, and resolve conflicts among group members (Wakefield, Leidner, & Garrison, 2008).

Emergent leadership also may be viewed as an inner perception of person's social status within the group, which often can (a) be represented through individuals' perception of leadership of themselves, and (b) be seen as a common perception of social roles by peers in the group. *Self-perceived leadership* is an inner perception of self in respect to the social status within the group (Avolio & Gardner, 2005; Hall, 2004). Two types self-perceived leadership include *task leadership* that deals with task accomplishments such as initiating structures and monitoring the process of the task, and *relational leadership* that facilitates team interactions such as maintaining closed relationships, and empowering and motivating group members (Burke et al., 2006; Yamaguchi & Maehr, 2004). *Peer-nominated leadership* reflects how members perceive others' leadership role within the group. It often features characteristics such as competence, popularity, reputation, and authority (Avolio & Gardner, 2005; Bass, 1998). For example, with or without official leadership appointment, individual members could perceive themselves as leaders and others as followers in particular contexts or tasks. On the other hand, they could perceive others as leaders and themselves as followers.

Therefore, three facets of leadership in group-learning setting include outward characteristics and behaviors – engagement, self-perceived leadership, and peer-perceived leadership. These facets may dynamically influence each other during a group learning process. Leadership research literature suggests that self-perceived leadership may lead to the demonstration of active behaviors (engagement) with significant influences on learning performance (Kahai, Sosik, & Avolio, 1997; Carte, Chidambaram, & Becker, 2006; Gressick & Derry, 2010). Limited extant research further suggests that active learning engagement would help students to gain popularity and possibly would lead to establish a leadership status perceived by other members in a collaborative group (Xie, Yu, & Bradshaw, 2014). In addition, research suggests that the development of social status in collaborative learning groups is a gradual and continuing process that requires to be evolved over time. For example, Tuckman (1965, 1977) proposed that group development often goes through five stages of forming, storming, norming, performing, and adjourning. Xie, Miller, and Allison (2013) found that social relations in an online group learning community often go through multiple weaves of progressive development. These research findings lead us to believe that the development of emergent leadership could be a dynamic process where time, engagement, self-perceived leadership and peer-perceived leadership interact with each other and evolve among the members within a learning group.

In this paper, we report an investigation on how students' engagement and self-perceived leadership influenced their peers' perception of emergent leadership over time in a small group online collaborative learning setting. The following research questions guided the design of this study, conducted in an online collaborative learning setting:

- 1. Do time, engagement, and self-perceived leadership have an effect on peer-nominated leadership?
- 2. How do engagement and self-perceived leadership influence peer-nominated leadership over time?
- 3. What are the qualitative characteristics do students report to describe the peer-nominated leaders?

Methods

Participants and context

The study involved undergraduates who were taking an elective online study-strategies course at a large public university in the Midwest United States during spring 2013. In total, 170 students from six sections of the course participated. Participants were 63% White, 8% African American, 8% Asian, and the remainder 21% was of other racial backgrounds. The distribution of gender was roughly equal, with males (42%) and females (49%). 9% of students did not report their gender. In terms of college experience, 13.6% were first-year students, 26.5% were sophomores, 20.6% were juniors, and 31.8% were seniors. 7.5% of students did not report their grade level. Students participated in five collaborative online discussions addressing the topics of note taking, reading, studying, presentation skills, and resilience. Students worked in groups of 5-7 in the discussions, which provided a forum for brainstorming ideas and coordinating process. Each discussion portfolio provided specific instructions and grading criteria, which covered expectations of both quality and quantity of the online discussion posts. At end of each week, students in a group were asked to nominate a group leader and provided the rational for their nominations. To provide insight into students' perceived leadership, students also completed a confidential online survey at the end of the semester. Students provided consent for the use of their coursework and survey responses for this research study.

Measures

Measures of this study include self-perceived leadership, peer-nominated leadership, and online engagement.

- Self-Perceived Leadership. Students' perceived leadership was measured on a seven-point Likert scale, which was adapted from Yamaguchi and Maehr's (2004) leadership scale. It consists of task-oriented (4 items) and relationship-oriented (5 items) leadership scales, measuring management of activities and interpersonal processes, respectively. Sample items, means, medians, standard deviations, and Cronbach's alpha reliabilities of the scale are presented in Table 1.
- **Peer-Nominated Leadership.** During the five-week research period (week 6-10), students were asked to nominate the emergent leaders for each week; therefore, the *number of peer nominations* was employed as a measure of students' emergent leadership. Peer nomination data were collected in each week with total 5 times during the course of the study.
- **Online Engagement**. Total numbers of students' authored discussion posts in the five weeks were used as the measure for students' engagement in the online course. The engagement data were aggregated into five data points to represent students' online learning engagement for each of the five weeks.

Table 1: Mean, standard deviations, and reliability statistics of perceived leadership scale

Variable	Sample Item	Mean	SD	α
Task Leadership	I gave the directions about how to do the online discussions.	4.01	1.49	.87
Relational Leadership	I tried to get everyone to work together.	3.98	1.41	.88

Findings and discussions

Quantitative findings

To answer the first and second research questions, repeated measures ANOVA was conducted to examine the interaction between students' perceived leadership and engagement and to link the interactions with the five time points in a person-centered analysis, the perceived leadership scale and engagement were dichotomized using a median-splits method (Midgley & Urdan, 2001; Pintrich, 2000). This procedure allowed for the use of repeated measures ANOVAs with multiple independent variables. Taking the task-oriented leadership variable as an example, student scoring below 4.0 were classified as low task leadership (LTL) and those scoring 4.0 and above were categorized as high task leadership (HTL). This resulted in 48% (n=81) classified in LTL group and 52% (n=89) in HTL group. The same method was applied to the perceived relationship-oriented leadership scale and engagement data. Table 2 represents the grouping results through the median splits method.

					Average Peer Nomination				
Factor	Median	Group	Ν	%	Week 6	Week 7	Week 8	Week 9	Week 10
Online Engagement	16	Low	81	48%	.35	.33	.35	.21	.41
		High	89	52%	1.07	1.07	1.17	1.20	.96
Task Leadership	4.0	Low	81	48%	.54	.44	.48	26	.43
		High	89	52%	.89	.97	1.04	1.16	.93
Relational Leadership	4.0	Low	79	47%	.67	.67	.61	.42	.57
		High	91	53%	.77	.76	.92	1.00	.80

Table 2. Grouping through median splits method

Then, repeated measures ANOVAs were performed using perceived task-oriented leadership, relationship-oriented leadership, and engagement variables as the between-subject factors, the five time points as the repeated measures factor, and peer-nominated leadership on the five week points as the within-subject factors. The analysis generated two general tests of significance that are relevant to the research questions.

Do time, engagement, and self-perceived leadership have an effect on peer-nominated leadership?

The within-subject analysis showed that there was an overall significant interaction effect of time, perceived leadership, and online engagement on students' emergent leadership nomination $[F(4,648)=2.35, p=.05, \eta^2 = .01]$. However, no significant main effects were found in the individual within-subject factors – time, perceived leadership, and online engagement. These results suggest that time, engagement, and self-perceived leadership alone did not significantly influence peer-nominated leadership. However, together, they had significant impact on the emergent leadership perceived by other members in a learning group.

How do engagement and self-perceived leadership influence peer-nominated leadership over time?

The between-subject analysis showed that after controlling the time effect, both perceived task-oriented leadership $[F(1,162) = 53.29, p < .001, \P^2 = .06]$ and engagement $[F(1,162) = 18.84, p = .002, \P^2 = .15]$ had significantly positive effect on students' emergent leadership nomination. Specifically, as shown in Figure 1.A, students who were in high-engagement group were more likely to be nominated as the group leader throughout the five weeks than those students in low-engagement group. As shown in Figure 1.B, students in high-task-leadership group were more likely to be nominated as the group leader throughout the five weeks than those in low-engagement group. As shown in Figure 1.B, students in high-task-leadership group. However, as shown in Figure 1.C, there were no significant differences in the peer nomination between the high-relational-leadership and low-relational-leadership groups. In addition, no significant interaction effects were found in the between-subject factors – perceived leadership and engagement.

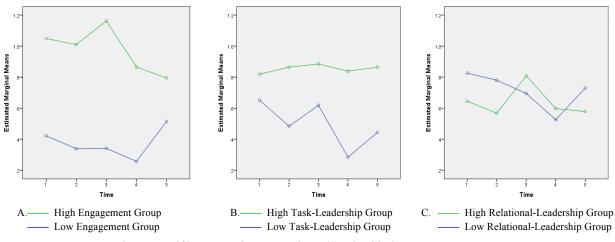


Figure 1. Differences of peer-nominated leadership between groups

In summary, the quantitative results indicated that emergent leadership perceived or nominated by peers in a group not only requires individuals' active engagement and self-perception of their leadership role, but also requires the leadership to be developed over time. High levels of perceived task leadership and active engagement would lead to more likelihood for individuals to be perceived by peers as emergent leaders in a group.

Qualitative findings

What qualitative characteristics do students report to describe the peer-nominated leaders?

In this asynchronous online course, main class activities were facilitated through the weekly online discussions. Therefore, the posting records in the discussion board would reflect the most frequent and visible learning activities where students interacted with each other. The reasons of the leader nomination, therefore, focus around various posting behaviors. By the end of each week, in the nomination surveys, students were asked to nominate one or more leaders in the group and provide justifications for their nominations. Six primary reasons emerged in the qualitative analysis through open coding combined with interpretive coding (Merriam, 1998). The results are delineated in Table 3.

First, 199 instances were identified from the data indicating that the *quality of posts* was the primary reason determining students' nomination. Students indicated appreciation to those posts that had highly relevant, original, thoughtful, and well-structured contributions to group knowledge building. While students spoke highly of the nominees' high-quality posts, they also demonstrated their disappointment on those posts with repeated opinions or being poorly structured.

Second, students generally perceived leadership by receiving the leaders' *active facilitation*. 167 instances were coded relevant to this theme. Timely coordination and replies with constructive suggestions benefited students when they had questions or confusions in group learning. Students tended to recognize individuals as leaders who are willing to voluntarily keep the group functioning and capable to understand, analyze, and solve other students' problems.

Third, 106 instances revealed another critical reason for their nomination, that is, the *quantity and diversity of posts* made by the leaders during online group discussions. Emergent leaders not only gave a large number of posts in the discussion board, but also responded to a wide range of group members. Students recognized that emergent leaders did read posts authored by various group members, and gave at least a reply to almost everyone in the group. In addition, emergent leaders actively and consistently participated in group throughout the entire one-week learning period.

Fourth, 97 instances indicated that *initiation of interaction* in a group discussion is an explicit leadership behavior through posting in the online discussion board. Initiation means that the post is published to the group prior to any other posts under a certain discussion topic. Students also indicated that they regularly reviewed others' posts before writing their own posts. The initial post that started the discussion of the week often led the direction of the discussion for this week. Students who made the initial posts, therefore, naturally had been perceived as the leader and the moderator of the week.

Fifth, 87 instances denoted that students perceived those who practically made a *significant* contribution to the group tasks as their leaders. The leaders completed the major group tasks (i.e., making the

presentation slides, turning in the final paper) or made important decisions (i.e., deciding the topic of group project).

Finally, 22 instances revealed that students were motivated to participate in class activities by those emergent leaders. The leaders *promoted others' motivation*. For example, students reported that they had to read and post more because of the emergent leaders' active engagement, and frequent and timely responding. Some responses from the emergent leaders gave advice to students in an encouraging tone, and made the author feel emotional and motivated on their own learning.

Table 3.	Reasons	for	nomination	with	sam	ple c	uotes

Nomination Reason	Ν	Sample Quote
1. Quality of Post	199	[His opinion is] significantly different from the rest of the group. She provides well-formatted arguments and presents good ideas. [The student made] concise quote that made a number of compelling points.
2. Active Facilitation	163	[The student] replied to many of the posts using constructive tips. She did a lot in terms of keeping everyone on track and making sure we got things done.
3. Quantity and Diversity of Posts	106	 She is always constantly posting throughout the week [The student] provided feedback on everyone's comments. [The student] tried to give her input to every person's post. [The student] contributed the most and offered the most input among all the group members.
4. Initiation of Interaction	97	He started off this week's conversation. She was the only person in our group who had posted an initial discussion!
5. Significant Contribution	87	[The student] created the presentation and completed a lot of the skeleton chart. He was the one to suggest module 2 as our topic and put the PowerPoint together.
6. Motivating Promotion	22	She gave me some tips along with being encouraging. This differs from some people who just comment on a post for credit. I believe his comments are substantive.

In addition, the absence of the six factors often led to non-nomination behavior which happened when student chose to not nominate anyone in the group as the emergent leader. Some students who chose not to nominate anyone provided explicit reasons, such as, a late start-up post, lack of responses, little knowledgeable input, or a failure of receiving help from the group. The non-nomination denoted that students perceived a lack of leadership in their group.

Conclusions and implications

The present study made an initial attempt to reveal the nature of leadership emergence in small group online collaborative learning. Beyond a common sense, the study provided the quantitative evidence to argue that the factors – time, engagement, and self-perceived leadership – have a significantly interactive effect on the peer-perceived leadership. This means the emergent leadership perceived by peers in a group requires individuals' active engagement and self-perceived role of task leadership are the two essential indicators for the emergence of leadership. The students who perceive themselves as the leader in the learning group and actively engage in group discussions are more likely to be nominated as the leader by peers, vice versa. This could provide guidance for designing and managing online group activity where emergent leadership is needed (such as doing a synthesized group project).

Furthermore, both quantitative and qualitative findings suggest the importance of meeting students' need of being supported by leadership. For example, the six main reasons of nomination outline the qualities of an ideal leader that students expected their leaders to have in their group. The matching degree between what the students expected for leadership and what the learning environment provided could be a diagnostic perspective for teaching practitioners to examine different collaborative online learning context.

Last but not least, the findings would help online students to better understand that the conflicts between self-perceived and peer-perceived leadership roles may exist in online collaborative learning activities. Further instructional design could be guided by the present study for helping students coordinate self-perceived and peer-perceived leadership role.

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Epistemography and Professional CSCL Environment Design

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Abstract: This study uses the epistemographic method to examine how professionals link ways of doing, thinking, and knowing in an epistemic frame that guides their reflection-inaction, which can inform the design of professional computer supported collaborative learning (CSCL) environments. This study examines student engineers learning design in a co-op program at a manufacturing company to investigate how participant structures, activities, and pedagogies are connected to an epistemic understanding of the profession. The analysis describes the significant participant structures in the engineering co-op program and the pedagogical techniques that are used in these participant structures. The analysis suggests that participant structures and pedagogical techniques are both orchestrated by and orchestrate the development of one of the central epistemological features of collaborative engineering design. These results suggest that epistemographic analysis is a useful tool in the development and analysis of professional CSCL environments.

Keywords: epistemology, reflection, participant structures, design, engineering, practicum, professional

Background

In this paper, we examine the method of *epistemography* as a tool for analyzing collaborative problem solving and this as a tool for developing computer supported collaborative learning (CSCL) environments based on realworld collaborative learning environments. To do this, we conduct an epistemographic analysis of an engineering practicum.

Collaborative work on complex problems is a fundamental aspect of engineering. Most problems that engineers address are ill-structured, meaning there are many acceptable solutions and no definitive procedures to follow to produce or determine a best solution (Cross, 1994; Dym, 1994). In order to understand how professionals manage ill-structured problems, Schön (1987) argues that professionals work by accessing a "repertoire of examples, images, understandings, and actions" (p. 66) that ranges across various design problems and finding a comparable situation to the problem at hand. Schön (1987) calls this method *reflection-in-action*: a way that professionals adapt to unexpected situations that arise in design problems without interrupting the flow of activity in progress. But not all problems in engineering—or in any ill-structured domain—are open-ended in this sense. Some problems do have known solution pathways, and thus part of professional reflection-in-action also has to include the ability to recognize and solve well-formed problems.

How, then, do engineers learn the forms of reflection-in-action that characterizes their profession? Decades of research in the learning sciences shows that learning to engage in a practice, such as engineering, is a social and situated process (Anderson, Herbert, & Simon, 1997; Bandura, 1986; Lave & Wenger, 1991). It requires initiation into a community of practice—a group of people who share ways of working, thinking, and acting in the world (1999).

In professional communities of practice, novices engage in a professional practicum where they participate in the practice under the guidance of senior practitioners, or mentors (Schön, 1987). In engineering professional practica, students learn to solve design problems by engaging in actions within the practice environment. In some practica, the student is asked to start designing before he even knows what designing means. (Schön, 1987; Shaffer, 2007b). Reflective discussions between mentor and student can occur within different participant structures—different "patterns of involvement that structure a particular kind of situation within a given practice" (Shaffer, 2005, p. 7). For example, Schön argues that there are several possible combinations of who is doing the acting and who is doing the reflecting. A mentor may demonstrate a task, and a student may watch and reflect upon the mentor's demonstration. Conversely, a student may produce a design drawing that the mentor critiques. In Schön's work, these forms of reflection-on-action are treated as variations on a theme, but without a taxonomy or distinction as to when one or the other form might be preferred or should be used.

Shaffer (2007a) has characterized the learning that occurs in participant structures within a practicum in terms of an epistemic frame—collections of skills, knowledge, identities, values, and epistemologies that are

connected in specific ways. Epistemic frame theory suggests that professionals rely on domain-specific skills and knowledge to make and justify decisions. They have characteristics that define their identities as members of the group, as well as a set of values they use to identify important issues and problems in the field. From this perspective, developing an epistemic frame means making a network of connections between these skills, knowledge, identities, values, and epistemological elements that are characteristic of the community. For example, in the engineering epistemic frame, an engineer might make a design decision to increase the safety factor of a product for the wellbeing of the client based on a completed stress analysis. In this case, the engineer is justifying the design decision by valuing the safety of the client and executing the skill of completing a stress analysis. She knows which values to consider and what information and skills to gather in order to make a design decision. Thus, one goal of a professional practicum is to build an epistemic frame.

The development of students' epistemic frames through such experiences can, in turn, be quantified using *epistemic network analysis* (ENA) (Shaffer et al., 2009). Because the learning that takes place during a practicum can be characterized by the connections between elements of a professional frame, ENA measures when and how often students make such links during their work. ENA creates a network model in which the nodes of the network represent the skills, knowledge, identity, values, and epistemology from a domain. The links between these nodes quantify how often a person has made connections between these elements at some point in time. In this way, ENA models the development over time of a student's epistemic frame—and thus quantifies their ability to think and work like professionals.

Investigating the epistemic frames of professional practices involves conducting an *epistemography*, an ethnographic analysis of the structure of a professional practicum through the lens of epistemic frames (Bagley & Shaffer, 2010; Hatfield & Shaffer, 2010). For example, Nash and Shaffer (2013) investigated the field of game design where the observed students and mentors interacting in a studio-style practicum. By examining the significant participant structures in the practicum, their analysis revealed a particular form of epistemic mentoring that mirrored a coaching model where mentors and students took indirect and unexpected path during the learning process. In general, epistemographies focus on participant structures of reflection and the overarching epistemologies that guide those structures.

In this study, we look at how an examination of the epistemological underpinnings of a professional practicum shed like on the pedagogical process of learning through reflection-on-action described by Schön (1987). In doing so, we argue that such epistemological inquiry is a useful tool in the development and analysis of CSCL environments.

The environment we analyze is an engineering co-op experience for college students. This study uses the epistemographic method to examine how professionals link ways of doing, thinking, and knowing in an epistemic frame that guides their reflection-in-action in ways that can inform the design of CSCL environments. More specifically, this study examines student engineers learning design in a co-op program at a manufacturing company to investigate how participant structures, activities, and pedagogies are connected to an epistemic understanding of the profession. We do this by addressing three research questions:

- 1. What are the significant activities in the engineering co-op program?
- 2. What are the participant structures of reflection that are used in those activities?
- 3. How do the participant structures of reflection relate to the epistemologies of the engineering co-op?

Methods

Participants, setting, and data collection

GammaCorp is a global engineering company that designs and manufactures high pressure hydraulic pumps and industrial tools. This study was conducted at a GammaCorp company branch and focused on two students who were new to the co-op at the time of the observations, including Kate, two students who had been in the program for several months at the time of the observations, including Noah and Amir, as well as six senior engineers who interacted with the students at various times, including Allen and Robin. All names used here are pseudonyms, and no demographic information was collected about the participants.

Data was collected in two forms: observations and interviews. A researcher was present as an observer for ten days from June to August. This included two project management meetings and seven meetings between engineers and students. Observational data was collected data in the form of audio recordings and field notes. Interviews were conducted with the four students and two engineers.

Data analysis

Observations and interviews were segmented into utterances—every time a participant took a turn to speak during a conversation. Using a grounded theory approach (Glaser & Strauss, 1967) a coding scheme was developed representing activities, pedagogies, and the key knowledge and epistemological stances of the co-op:

- **Problem Solving:** Development of a solution to a technical issue as part of an engineering design
- Documentation: Completion of forms and other written documents describing a design
- Feedback: A critique about a design artifact or design idea or an informative or corrective suggestion.
- **Modeling:** Using a tool or exemplar to demonstrate a task or idea.
- Customer Knowledge: Referring to the customer
- Technical Knowledge: Referring to technical or mathematical concepts.
- Epistemology of Translating Customer Requests to Technical Requirements: Describing engineering design in terms of using technical knowledge to address the customer requests
- Epistemology of Translating Technical Requirements to Customer Requests: Describing engineering design in terms of explaining technical requirements and details of the design to the customer

Two types of activities were identified: problem solving and documenting. Two main types of pedagogies were identified: feedback and modeling.

Epistemic network analysis (ENA) was used to investigate the underlying relationships among the activities, knowledge, and epistemologies of engineering as expressed by participants in interviews and observation. ENA has been described in greater detail elsewhere (Shaffer, 2014; Shaffer et al., 2009), but in brief, ENA models coded data by grouping the utterances (in this case answers to interview questions for a given participant) and producing an adjacency matrix for each utterance to determine which codes are linked (that is, which ones co-occur).

To identify patterns of connections in the data, ENA sums the adjacency matrices for each participant u into a cumulative adjacency matrix, C^u , where each cell C^u_{ij} represents the number of stanzas in which a codes i and j were both present. These cumulative adjacency matrices are then converted into network graphs in which each node corresponds to a code from the coded dataset and lines connecting nodes represent co-occurrences of codes in the data. Thicker lines correspond to stronger connections in the data between elements of discourse in the model.

Results

The results of this study are described in three parts below. First is a description of the two main activities of the co-op: problem solving and documenting. Second is a description of the two main pedagogical methods of the co-op: feedback and modeling. Finally, we examine the relationship between the activities and the pedagogy through the lens of a key epistemological element of the engineering practice.

Activities

The design work of co-op students at GammaCorp consists of two main activities: problem solving and documentation.

Problem solving

During the problem solving process, students attempted to meet the requests of the customer by either designing a unique solution or modifying previously made solutions. For example, midway through Amir's program after he had some experience working at the company, he was asked to design a tow cart that would house a variety of tools. When Amir received the task, a sales representative at the company had "quoted it out" to the customer. This meant that the customer already had an idea of how much the product would cost and had explained to a sales representative what he expected from the product. Amir received the quote and the customer's requests, which gave him an approximate budget and some direction on which parts to use to design the cart. Amir summarized the requests, "They want this design pump. They want it to be a six-point lift system with all these full controls. They want to be able to store this all on this cart. They want storage for these hoses. And they want to be able to lift it and drive it around a shipyard."

When Amir received this information, he approached Allen, one of the senior engineers, to get more information on what his first steps should be. Allen explained that Amir had to find a way to build and design the cart using the CAD drawing tool. Allen suggested that instead of trying to design the final product, Amir

should first complete a minimal and basic design. Amir could then ask for feedback on the simple design, and then complete several iterations to design the details of the final product. Allen and Amir worked together on sketching some basic designs and discussed how the parts could potentially fit together. When Amir returned to his desk to work on designing the tow cart, he began by reviewing the sketches that he and Allen had made. After some trial and error with the CAD program, Amir figured out which pieces he could mount together and how they would fit collectively.

One week later Amir had a preliminary design, as Allen had suggested. He printed out the drawings and asked some engineers for feedback. Unfortunately, it did not go as well as Amir had expected. "They railed me on everything," Amir laughed as he recalled the meeting. For example, he had some hoses sticking out in many different places on the tow cart, which blocked the customer's access to the controls on the cart. The engineers asked that Amir make several changes and present the design to them once the changes had been made.

One week later, Amir showed the engineers a second design. This time the engineers asked Amir to make only minor changes. Once those minor changes were made and approved, Amir could finalize the design to send out to the customer.

Documentation

Once the customer approved the design, Amir had to document his work. First, he completed a part release form that released all the parts into the manufacturing system. This form ensured that the manufacturing line could produce and assemble all the parts needed for his tow cart product. Amir explained the importance of this documentation stage:

Basically anytime that we have anything new that is designed or a design that is based off of a part, we need to release a new part into the system with all the correct coding, cost information. We've got to get that all coded and get that released into our system, so that orders can be made. It can be a hassle, but it's something we need to do, need to be able to document everything that happened with it.

Next, Amir completed a *product requirements document* (PRD), which is a document that describes the specifications and functions of a product. The PRD also includes instructions for assembly or operation. After the product was assembled, he went down to the manufacturing area to take photos of the product. He wanted to file the photos so other engineers could see a final version of the product or use the photo to show future customers, in case another customer wanted to order something similar.

While this process was relatively smooth for Amir's cart design, co-op students often needed help completing this part of their work For example, one month into the program, Kate had some difficulty with documentation for a customer's order: She didn't know what product numbers she should use. She thought she needed an "M" product number, but she didn't know how to find the right number. One of the more senior co-op students, Noah, tried to help, but he didn't know either. So Kate sent an instant message to Robin, one of the senior engineers.

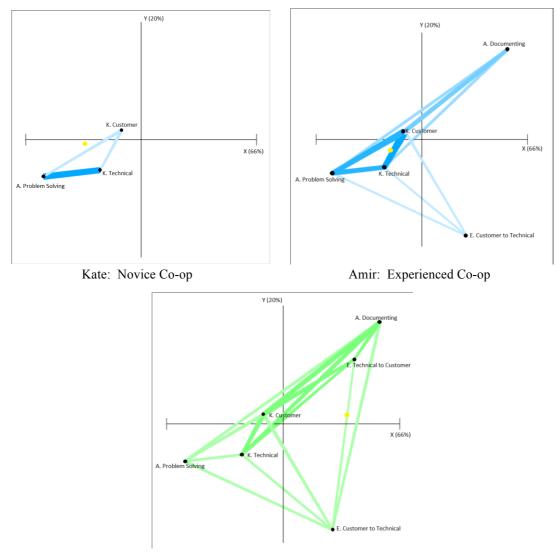
When Robin arrived, she examined the documentation on Kate's the computer. Noah said that he thought they were supposed to release the "M" parts for manufacturing. Robin explained that there were two forms of documentation to complete because there were two parts of the design that needed to be documented. Then she leaned over the computer to use the keyboard and showed Kate and Noah how to complete the documentation. Kate asked several questions about how to document, and Robin responded by showing her what forms to use and where to find the part information to complete the documentation.

Participant structures of reflection

The examples in the previous section of the results show two distinct forms of activity in the co-op, each of which is a form of reflection-on-action:

In the problem solving activity, the student (Amir) engaged in action by creating a design artifact. He presented this artifact to his mentors, who reflected on the student's action by providing feedback. In other words, in this example of problem solving, the main form of reflection-on-action was the *mentor reflecting on student action*.

In the documentation activity, the students (Kate and Noah) initiated the meeting with a mentor. But then the *mentor* took action by completing the appropriate forms while the students watched. The students then reflected on the mentor's action by asking clarifying questions. In this example of documentation, the main form of reflection-on-action was the *student reflecting on mentor action*.



Robin: Senior Engineer

Figure 1. Epistemic Network Models for Co-op students and Engineers

This pattern of association between activity and pedagogy was true generally throughout this practicum. Student reflection on mentor action occurred mainly during documentation and mentor reflection on student action occurred mainly in problem solving activities (see Table 1; difference significant using Fisher's Exact Test at p < .01).

	Feedback	Modeling
Problem Solving	6	0
Documenting	1	14

Epistemology

The epistemologies of translation

This part of the results section explores the epistemological foundations of engineering design as practiced at GammaCorp that may explain this correspondence of activity and the participant structures of reflection. Specifically, we note that a critical element of engineering thinking at GammaCorp is the *epistemology of translation*, which appears in two forms: *translation of customer needs into design specifications*, and the reciprocal *translation of the resulting design specifications into a form understandable by the customer*.

First, we note that the development of these epistemologies of translation is a key component of professional expertise. ENA models of participant interviews about their practice show progressive integration of the epistemology of translation between customer and the technical space of design and also the epistemology of translation back from the technical aspects of a design to customer as engineers become more advanced in their training.

Three of these networks are shown in Figure 1 above. These models suggest that both novice and experienced students made fewer connections to the epistemologies of translation than senior engineers. For example, Kate described the importance of technical knowledge and customer knowledge while problem solving, but never connected these skills and knowledge to an understanding about why engineers work in the way they do:

There is this big piece of equipment, and they need to something to sit on, because they just have to mount some wood.

Amir, a more senior student, made strong connections in his network between problem solving and technical knowledge and customer knowledge. However, he also connected this knowledge to the epistemology of translating the technical design into a form understandable by the customer:

A big part of this was going to be that *I wanted to have the customer be able to operate everything* on this Tow Cart standing from one point.

Robin, as a senior engineer, had a network with more robust connections to the epistemologies of translation than either of the students. Further, Robin's network shows that the activity of documentation is very closely connected with the epistemology of translation from the technical world of design to the customer.

Differences between the epistemologies of translation

The processes of *translation from customer to design* and *translation from design to customer* both exist within the ill-structured world of design. However at GammaCorp, the process of translation from design to customer is a relatively constrained activity within the broader design process. The actual product is already designed. The task that remains for the engineer at GammaCorp is to communicate the salient details of design to the client through the company's documentation software. In the first week of the co-op program, students attended a training session on how to use the documentation tools. This training took place in a classroom setting; an engineer distributed a manual, projected the software tool on a screen, and reviewed the manual page by page. Afterwards, students completed exercises in the manual. The epistemology of translation from design to customer is algorithmic: there is a specified process to follow. Determining which process to use may be complex, but the process itself follows clear guidelines. As Noah, one of the student co-ops, described it: "It's pretty... it's not like it's confusing, but it is at the same time."

In contrast, when students engage in problem solving, there are few clearly defined procedures. There were no manuals or training classrooms at the beginning of the co-to teach students to solve design problems. Instead, students were given a broad task to accomplish and came to the more senior engineers for feedback. For example, Amir said that his work as a co-op began when one of the engineers "basically gave me a rundown of what was expected of me. Basically I had to create an ID drawing of everything once I had designed the frame and everything and... we should have the really basic design done before getting into too many specifics." In other words, the epistemology of translation from customer requirements to artifact design is fundamentally more ill-formed than the process of documenting the results of a design.

Discussion

Two cycles of translation

The results above suggest that design in this engineering practicum was a combination of two different cycles of action and reflection-on-action. Moreover, the participant structures of reflection in these cycles were shaped by two related but significantly different epistemologies of translation in the engineering design process.

Translating customer needs into a design

The students started with a design task and engaged in iterative problem solving in order to translate the customer requests into technical requirements. When students needed assistance with problem solving, they initiated meetings with engineers. The engineers offered feedback on the students' design. The students then

continued designing until they needed assistance again. This reflection cycle continued until the engineers collectively decided that the students had designed a solution that met the client's requests. But a fundamental property of the problems solving process was epistemological: there was no clear right answer or even single best way to go about developing an answer. The epistemology of translation from customer requirements to finished design was ill-structured, and the reflection-on-action in this context was structured as *mentor reflection on student action*.

Translating a design back to the customer

Next, students documented the design in order to translate the technical requirements into a form that was interpretable by the customer. Similar to the problem solving activity, if students were unsure of how to document a product, they initiated meetings with senior engineers. However, in meetings that centered on documentation, engineers modeled procedures and the students asked questions. A fundamental property of the documentation process at GammCorp was also epistemological: there *was* a right way to communicate the relevant features of a design to the client using GammaCorp's documentation tool. The epistemology of translation from customer requirements to finished design was relatively well-formed, and the reflection-on-action in this context was structured as *student reflection on mentor action*.

Engineering design translation cycle

In other words, this epistemographic analysis of an engineering co-op suggests that at GammaCopr there was a relationship between forms of activity and forms of reflection that can be explained by differences in the epistemologies that guide both. There are two independent reflection cycles within the larger design process. This model, which we describe as the Engineering Design Translation Cycle (Figure 2), exemplifies a particular method of thinking about engineering design.

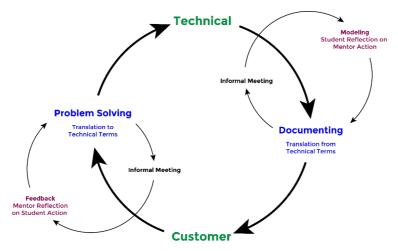


Figure 2. Engineering design translation cycle

The two forms of reflection-on-action—mentor reflection on student action and student reflection on mentor action—help students develop an epistemic understanding of translation between the customer and technical world. But importantly, one form of reflection—mentor reflection on student action—is associated with problem solving in design, an activity grounded in the epistemology of translation from customer requirements and the technical world of design, a decision-making process that is open-ended and ill-formed. Students are encouraged to explore the design space and get feedback from their mentors. The other form of reflection—student reflection on mentor action—is associated with documentation, an activity grounded in the epistemology of translation from the technical world of the design back to the language of the customer, a decision-making process that is relatively well-formed. Students are encouraged to watch a mentor enact the correct procedure and ask questions to generate and confirm understanding.

Implications

There are several key implications of this study for the CSCL community.

First, this work suggest that in collaborative learning contexts such as a practicum in ill-structured domains like engineering design there may well-formed activities that need to be accounted for in any learning

design. Second, this work extends Schön's characterization of the participant structures of reflection-on-action. It suggests that forms of reflection-on-action may be driven by the epistemological nature of the action being reflected on. In particular, in the case in question, mentor-reflecting-on-student-action was associated with ill-formed tasks, whereas student-reflecting-on-mentor-action was associated with more well-formed activities in the domain. These results have clear implications for any CSCL application designed for ill-structured domains where learning is characterized by cycles of action and reflection-on-action.

More broadly, though, this study suggests that the process of epistemography—the analysis of the epistemological features of a learning environment—is a useful tool for uncovering the rationale behind the participant structures of reflection, and perhaps of pedagogy more generally. Thus, epistemography—and its associated theory of epistemic frames and analytical method of epistemic network analysis—is a useful tool in the development and analysis of collaborative learning environments.

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The Burden of Facilitating Collaboration: Towards Estimation of Teacher Orchestration Load using Eye-Tracking Measures

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Abstract: Teacher facilitation of CSCL activities is widely recognized as one of the main factors affecting student learning outcomes in formal face-to-face settings. However, the orchestration load that such facilitation represents for the teacher, within the constraints of an authentic classroom, remains under-researched. This paper presents a novel method to estimate the cognitive load of teachers during facilitation of CSCL sessions, using mobile eye-tracking techniques. Throughout three studies of increasing authenticity, we demonstrate the feasibility of this approach, and extract insights about classroom usability challenges in CSCL practice: the increased load of class-level facilitation, or the real-time monitoring of students' progress. This new instrument in the CSCL researcher's toolkit can help focus our attention in critical, fine-grained classroom usability episodes, to make more informed design decisions.

Keywords: orchestration, cognitive load, eye-tracking, teaching, facilitation

Introduction

Although CSCL often focuses on distance or informal learning, the physical, the face-to-face classroom in formal education is still the most common CSCL setting for many learners across the world. In the everyday life of these classrooms, teacher facilitation of collaborative learning is considered one of the main factors affecting learning outcomes (e.g., Onrubia & Engel, 2012; Song & Looi, 2012; Gómez et al., 2013): although student interactions remain crucial in CSCL, we still expect teachers to prepare, manage, assess and even adapt CSCL activities in their everyday practice: what Dillenbourg, Jarvela & Fischer (2009) termed 'orchestration'.

CSCL research has proposed new technologies and innovations to support learning together, focusing greatly on their individual and small-group usability. However, the study of pedagogical usability of CSCL innovations at the classroom level (e.g., will this nicely-designed, computer-supported group interaction be manageable for the teacher when ten groups are working at the same time?) has not been in the center of attention until recently (Dillenbourg et al., 2011). First studies and guidelines on the 'orchestration load' of CSCL facilitation are starting to appear (e.g., Cuendet et al., 2013), although they mostly remain on a qualitative, high-level of abstraction. Having a wider palette of techniques to measure orchestration load, not only from a qualitative perspective but also in a more objective manner, can be essential to understand the limited uptake that many CSCL innovations have – a growing concern in our community (Chan, 2011).

In this paper, we explore a method to estimate teachers' load when facilitating CSCL activities in authentic face-to-face classroom settings, using mobile eye-tracking techniques. This exploration is composed of three studies conducted in different contexts: a) a first analytic study of the load when performing a simple task in a lab setting; b) an exploratory case study, in which a researcher facilitated three CSCL sessions with a total of 61 primary school children, in a multi-tabletop classroom; c) a case study in the context of a university masters course, in which an expert and a novice teacher facilitated three sessions with the same group of 12-14 students, combining lecturing and collaborative work.

The rest of the paper is structured as follows: after a section detailing the related background in the areas of orchestration, cognitive load measurement and eye-tracking, we describe the general methodology of our studies; then, the context, methods and result of the three studies are sequentially described; afterwards, we discuss the results of the studies and conclude with their implications for research on orchestration, and current and future work.

Related background

Orchestration and orchestration load

When CSCL is enacted in a formal educational setting, teacher facilitation can greatly affect the effectiveness of learning (Onrubia & Engel, 2012; Song & Looi, 2012; Gómez et al., 2013). In this direction, Dillenbourg, Jarvela & Fischer (2009) define orchestration as "the process of productively coordinating supportive

interventions across multiple learning activities occurring at multiple social levels". In this paper we will focus mainly on orchestration as the *run-time coordination of CSCL activities*, even if that might not be the only aspect that CSCL orchestration entails (Prieto et al., 2011; Roschelle, Dimitriadis & Hoppe, 2013).

In the literature we can find several examples of research efforts trying to address this run-time coordination in different educative contexts: Pérez-Sanagustin et al. (2009) implement flexible group management mechanisms on blended CSCL (computationally-interpretable) scripts, to automate the flow of learning activities. Muñoz-Cristobal et al. (2013) study how sharing the load of creating and managing learning artifacts can ease the orchestration of CSCL activities across multiple spaces. Cuendet et al. (2013) gather lessons learnt from several studies and propose five general design guidelines to lessen orchestration load when designing augmented reality technologies for the classroom. However, these works generally focus on qualitative, high-level conclusions about orchestration load, or ad-hoc measurements of orchestration efficiency (e.g., waiting time of students), based on a specific activity flow.

Dillenbourg et al. (2011) posit orchestration as "usability in the third circle", referring to the classroomlevel usability (as opposed to single user and group-level usability, the focus of many HCI and CSCW/CSCL research works, respectively). However, as we have seen, we currently lack a finer-grained, more objective way of measuring orchestration load of a CSCL innovation for the teacher/facilitator, which might complement current subjective assessments of orchestration load (e.g., gathering the teachers' feedback after using a technology). Thus, we ultimately aim at helping respond to questions like: Which moment of a classroom enactment poses more load? Which technology design alternative will make classroom facilitation easier?

Orchestration load could be said to have two main components: a) the physical/logistic load (e.g., moving around the classroom, writing on the whiteboard, distributing worksheets); and b) the cognitive load of assessing what is going on in the classroom, weighing different courses of action and taking decisions about how to best support the ongoing CSCL process. This latter kind of load is probably the most important of the two in many situations, but it is also quite difficult to observe directly. Fortunately, cognitive load has been extensively studied in other contexts by psychology and the field of human-computer interaction (HCI).

Measuring cognitive load

In cognitive psychology, cognitive load (CL) is related to the executive control of working memory, and the limited capacity of human cognitive processing capacity (Paas et al., 2004). Cognitive Load Theory (CLT), its most direct application to the learning domain, has been extensively used in CSCL and educational psychology in general, and has served to discover several effects that may hamper learning by producing unwanted extraneous CL: split-attention effects, modality effects, worked example effects, etc. (van Merrienboer & Sweller, 2005).

Multiple techniques have been used to measure cognitive load, which Brunken et al. (2003) classify along two dimensions: direct measures (targeting cognitive load itself) vs. indirect ones (targeting other constructs related to CL), and subjective measures (those relying on subject introspection and memory) vs. objective ones. For instance, researchers have tried to measure CL using self-report questionnaires (subjective, direct/indirect), brain imaging techniques (objective, direct), dual-task performance (objective, direct) or physiological measures such as heart rate monitoring or eye-tracking (objective, indirect). However, it is important to note that many of these techniques have been applied mostly to relatively simple tasks, under controlled lab conditions. The measurement of cognitive load in more complex everyday activities is still considered difficult and needs to be further explored (van Merrienboer & Sweller, 2005).

Eye-tracking and teacher cognitive load in authentic settings

As we have seen, cognitive load has been used extensively to study learning tasks – but could it be used to study teaching as well? Although cognitive processing is often mentioned in teacher education literature, papers that focus specifically on this topic are not common: as a rare exception, Feldon (2007) re-interprets findings from teacher education research in terms of cognitive psychology, and highlights the role of developing automaticity to drive teacher training effectiveness.

Although measuring CL during CSCL facilitation could play a crucial role in designing technology for classroom-level usability (in the same way that CLT helped design technologies more conducive to student learning), the activity of teaching presents a unique set of challenges to such measurement, especially taking into account that orchestration is, by definition, concerned with what happens in authentic, non-controlled classroom settings rather than laboratory tests (Roschelle et al., 2013).

Brain imaging techniques, while being a direct and objective measure of CL, has been found unreliable, even in lab settings, by Paas et al. (2003), and are difficult to implement in a classroom setting. The fact that teaching is a complex and demanding activity, leading to overload (especially in the case of novice teachers –

see Feldon, 2007) makes dual-task measurements of CL (i.e., posing a secondary task to perform simultaneously with the main one) too obtrusive (Paas et al., 2003). Subjective self-report questionnaires, when administered during a lesson, can be equally disruptive, or have to rely on the subject's general memory of a long stretch of time (e.g., 50+ minutes in a normal lesson time span). The fact that "performance" in teaching is very hard to measure and also rules out performance-based measurements of CL. This leaves us with physiological measures of cognitive load, among which eye-tracking is considered quite reliable (Paas et al., 2003).

Eyetracking techniques measure and analyze the eye movements (fixation into a point of attention, saccades to the next fixation point, pupillary dilation responses, all in the scale of milliseconds), as a window into human cognition (Holmqvist et al., 2011). Although traditionally performed in lab settings using fixed equipment, the appearance of mobile eye-trackers (e.g., in wearable goggles format) now makes it possible to study such physiological response in the context of authentic activities. The relationship between pupillary response and cognitive load (e.g., mean pupil dilation is correlated with CL) has a long history in ergonomics (Kahnemann & Beatty, 1966). However, this kind of measures are known to be sensitive to varying lighting conditions (which are bound to occur in an authentic classroom). There exist multiple eye-tracking measures that can be related to CL: Buettner (2013), for example, identifies four such measures (mean pupil dilation, pupil dilation standard deviation, number of long fixations, average saccade speed). Thus, the triangulation of multiple eye-tracking measures could provide a more reliable way to trace teacher while facilitating CSCL in authentic classroom settings.

Methodology

Against this background, our main research question is: *can we use eye-tracking techniques to follow cognitive load of teachers facilitating CSCL in authentic settings?* In order to explore this question, we set out to apply the measurement of the four metrics used by Buettner (2013) in three studies (with increasing degree of authenticity). The main goal and features of these studies are depicted in Table 1, and further details of the context and methodology of each study can be found in each of the following sections.

Study	Analytical	Semi-authentic	Authentic
Setting	Laboratory	Multi-tabletop classroom, lab 'open	Authentic course, classroom
		doors' day	including projector and laptops
Goal	Test method in different	Feasibility of eye-tracking within	Feasibility of eye-tracking in real
	task, see evolution of	classroom constraints, insights about	course, individual differences of
	CL over time	multi-tabletop classroom usability	novice/expert teachers
Subjects	16 participants	1 facilitator-researcher, 61 primary	1 expert teacher, 1 novice teacher,
		school students	12-14 students
Task	Game-based	Facilitation of small group	Mix of lecture and collaborative
		collaborative work	work
Study	128 games in total, 1.5-	3 sessions, 35-45 min each	3 sessions (2 expert, 1 novice),
duration	4 minutes each		45-65 min each

Table 1: Main characteristics of the studies

Analytical study: Cognitive load in a simple game-based task

As a first step in our exploration of eye-tracking to follow teacher cognitive load, and taking into account that eye responses are often task-dependent (Holmqvist et al., 2011), we devised a first *test for the validity of the measurements proposed in Buettner (2013)*. Using existing eye-tracking data from a previous experiment in which participants played a computer game (unrelated to the task in Buettner's study), we estimated the evolution of the CL of participants throughout their experience, to see whether the results were consistent with what we knew about the game task in question and its temporal evolution.

Context and method

The eye-tracking data for this study was gathered during the course of an experiment on reward systems, collaborative/competitive behavior and stress (Senn & Goette, in progress). In the experiment, 16 subjects had to play a game of Tetris, either in collaborative or in competitive mode, with another participant, for 8 games. The maximum duration (if there was no 'game over') for each game was 5 minutes. Eye-tracking measures (eye movements, pupil dilation) were recorded, along with different game variables (e.g., game points, height of the stack of blocks, etc.).

The four measures used by Buettner (mean pupil diameter, pupil diameter standard deviation, saccade speed and number of fixations longer than 500ms) were calculated for every participant and game using these

data, over a sliding window of 10 seconds (with a 5s slide from one window to the next). Then, a median cut was performed (using the median for each game), and a "load index" was calculated by counting the number of measures that were *above* the game median (thus going from 0 to 4), as a rating of how likely it is that a certain 10-second window represented higher cognitive load than other windows in that session. Then, this load index was compared with the two main game variables (the height and the variance of the stack of blocks), along the duration of each game (1).

Results

Figure 1a shows the average cognitive load index (brown curve) of participants as time went on, as well as the temporal evolution of the stack height (green curve) and stack variance (blue curve). If we think in terms of the particular task (the Tetris game), we get interesting insights into how the cognitive load evolves over time: at the beginning (low mean stack heights) the cognitive load is high (as many alternative options for placing a new piece are open to decide amongst), and it generally goes down as the game goes towards the end (higher mean stack height), until we eventually disengage from the game when we give up. Similar but opposite is the effect of stack variance (higher variance implies more complex stack profiles, difficult to process and with more open alternatives of placement). Figures 1b and 1c show the main descriptive statistics of both game variables on 10-second windows, classified by their load index. Our results show that the load index is positively correlated with stack variance, and negatively correlated with the mean stack height, and that such an effect is more clearly apparent in the extreme values of the load index.

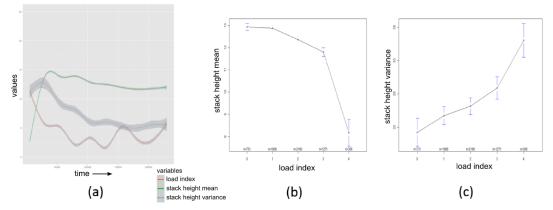


Figure 1. (a) Temporal evolution of averages of load index, stack height mean and variance; (b) and (c), stack height mean and variance in episodes classified by their load index

These results show that the load index, computed as described above, has potential for distinguishing different kinds of episodes occurring during the task (represented by moments with different mean stack heights and variances). We also see how CL may be related with the amount of *open alternatives* in each moment (in a sense, the uncertainty or the 'entropy' we perceive about the current game situation).

Semi-authentic study: Multi-tabletops at an open-doors day in the lab

Although playing Tetris is certainly far removed from the activity of teaching, the aforementioned results encouraged us to attempt the application of similar methods to the analysis of teacher facilitation of CSCL in a real-life setting. Thus, for the next study we aimed to explore the following research questions: *is it feasible to use a mobile eye-tracker to follow CL in a semi-authentic classroom setting? Does such analysis provide interesting insights about classroom usability of a novel CSCL technology? Can we detect specific classroom interaction episodes that imply high (or low) cognitive load?*

Context and method

The study was conducted in the context of an open doors day in our lab, in which whole classrooms of students from nearby primary schools had the chance to experience new learning technologies. In this occasion, a room was set up with five augmented paper tabletop devices running an augmented-paper tabletop collaborative learning software about mathematics (see Figure 2, and Caballero et al., 2014 for further details). A researcher (a novice in teaching to primary school children) played the role of the teacher/facilitator in this simulated math lesson about fractions, assisted by two other researchers and with the presence of two of the usual school

teachers acting as observers, during approximately 40 minutes. In total, 61 primary school students (10-12 years old) attended these sessions.



Figure 2. Setup of the multi-tabletop classroom and facilitator wearing mobile eye-tracker (left). User interface of the collaborative augmented paper game used by students during the session (right)

Again, eye-tracking measures of eye movement and pupil dilation were recorded, and a load index was calculated for (sliding) windows of 10 seconds (in a similar way as for the previous study). From this set of 10second episodes we selected those that had minimum (0) or maximum (4) cognitive load index (as we saw in the previous study that the load index had more contrasting power in these extremes), and performed a qualitative video coding of them, to assess the main trends/patterns in orchestration properties of high/low load episodes. Taking into account the definition of orchestration by Dillenbourg, Jarvela & Fischer (2009, see 'Related work' section), each episode was coded along three dimensions: the *activity* or intervention the teacher was performing (explanation/lecture, monitoring, task distribution, repairs...), the *social plane* at which the activity was intended (individual, group or classroom level) and the *main focus* of the teacher's gaze during the episode (including students' faces or backs, the tabletop surfaces, the teacher desk, etc.). More details about the context and method used can be found in Prieto et al. (2014).

Results

A statistical analysis (Pearson's chi-squared test of independence) of the video coding for the episodes with minimum and maximum load index (n=315) revealed that high-load and low-load episodes had *statistically* significant differentiated profiles in all three coding dimensions: teacher activity ($\chi^2 = 15.3434$, df = 3, p = 0.001546), activity's social plane ($\chi^2 = 123.2922$, df = 1, p < 2.2e-16) and the main focus of teacher's gaze ($\chi^2 = 252.1052$, df = 7, p < 2.2e-16). By looking at the contributions of the different video codes to this statistical difference (the chi-squared test residuals for each code), we could identify the distinct profiles of high- and low-load episodes (i.e., what where the video codes appearing typically in one case or the other): high-load episodes had a higher chance of being transition/task distribution activities, and to occur at the classroom-level, featuring the students' faces (e.g., when explaining) or backs (e.g., when monitoring the progress of activities), or the teacher's own desk, which was cluttered with multiple paper elements to be distributed to the student groups as they progressed along the lesson activities. In contrast, *low-load episodes* occurred almost exclusively at the group social plane, while the teacher was focusing exclusively on one student tabletop.

The results of this study illustrate that it is feasible to use eye-tracking in a semi-authentic CSCL situation (e.g., the calibration procedure needed at the beginning of the eye-tracker recording could easily fit at the beginning of the lesson), and that the load index calculated using such techniques can be used to distinguish high/low load episodes. This enables focusing the researchers' attention in a smaller number of critical classroom usability episodes with distinct profiles (e.g., classroom-level activities have higher chance of high cognitive load). Furthermore, the study provided certain insights into classroom usability aspects of the specific CSCL technology used in this classroom: the need for classroom-level monitoring support in multi-tabletop classrooms and the dangers of a cluttered augmented paper user interface.

Authentic study: Master-level university course

After the promising results of the previous two studies, we set out to explore the following research questions: *is it feasible to use mobile eye-tracker to follow cognitive load in an authentic classroom/lesson?* But also, since eye movement patterns can vary greatly from person to person (Paas et al., 2003) and cognitive overload is known to be related to teaching expertise (Feldon, 2007), we aimed at exploring a second question: *do teachers with different teaching experience show different load episode patterns?*

Context and method

This study was performed in the context of a real master-level course at our university, on the topic of learning analytics and digital education. In this course several teachers and teaching assistants facilitate the different course sessions, which often combine lecturing and collaborative problem solving. We selected two of these teachers (one with more than ten years of teaching experience, the other a teaching assistant with two years of sporadic teaching assistantship), and recorded three course sessions of 45-65 minutes, with 12-14 students attending the class (two sessions for the expert teacher, one for the novice teacher). All sessions interspersed explanation/lecturing on the part of the teacher, with student individual and collaborative work (using laptops), and later debriefing of student outcomes. Thus, they represented the variety of situations and activities that often appear in authentic classroom settings.

The data gathering and analysis followed the same schema as for the previous study: recording of eyetracking data using a mobile eye-tracker, calculation of the load index over 10-second episodes. From this load index, maximum and minimum load episodes were extracted and video-coded (along the same three dimensions of activity, social plane and main gaze focus). Then, statistical tests were run on the resulting video codes to check for the significance of the differences among video code distributions of high- and low-load episodes (both overall, and at the participant-teacher level).

Results

Again, a chi-squared test of independence of the *overall* video coding for the episodes with minimum and maximum load index (n=242) revealed that high-load and low-load episodes had statistically significant differentiated profiles in all three coding dimensions: teacher's activity ($\chi^2 = 9.904$, df = 4, p = 0.04208), the activity's social plane ($\chi^2 = 14.8271$, df = 1, p = 0.0001178) and the teacher's main focus during the episode ($\chi^2 = 45.2066$, df = 7, p = 1.247e-07). In this case, looking at the most significant residuals of the chi-squared test, the profile of the *high-load episodes* again featured more often classroom-level activities, the monitoring of student work, and a focus on student faces, backs, or the whiteboard. *Low-load* episodes were most often repairs (e.g., solving a student doubt) at the individual or group level, when looking at the teachers' own computer/desk.

However, if we analyze the high- and low-load episodes at the level of *each participant teacher* (and the statistical test's residuals), we find interesting commonalities and differences: while for the novice teacher the high-load episodes gather more clearly under the classroom-level social plane (p = 6.992e-05), for the expert teacher such trend, while present, is *not* statistically significant (p = 0.2445). The same occurs for the teacher activity: while for the novice teacher the high-load episodes often feature monitoring, explanation or transitions, and the low-load ones are most often repairs (p = 0.000269), for the expert teacher such a trend is *not* significant (p = 0.4959). Regarding the main focus of teacher's gaze during the episodes, in both cases the differences are statistically significant (p = 0.00132 for the expert teacher, and p = 1.966e-06 for the novice one), with high-load episodes focusing on student faces or on the whiteboard, while low-load ones are most often focusing on the teacher does are statistically, in all cases, are smaller in the case of the expert teacher).

The results of this third study confirm some of the findings of the previous studies in this series (the increased load of classroom-level activities, or in trying to read students' faces, probably to assess their understanding). They also served to spot cognitive load patterns between an expert and a novice teacher (novice's high CL episodes being more concentrated in distinct kinds of activities/focus than the expert's). Finally, this study further confirms that this method for following CL of a teacher/facilitator is usable in authentic situations (although it requires the presence of a researcher/assistant for calibrating the device).

Discussion and future work

Overall, the three aforementioned studies show that the proposed combination of mobile eye-tracking measurements can be feasibly used in authentic classroom settings (2). Together with post-hoc qualitative video coding, the approach also showed potential for discriminating fine-grained critical episodes (either high- or low-load) during the CSCL enactment, without having to rely on the teacher's memory of the events. The distinct profiles of such episodes have helped us gain insights into the difficulties of orchestrating CSCL activities. Some of these results had already been anticipated by existing work on orchestration load: the need for awareness/monitoring support in multi-tabletop classrooms (Kharrufa et al., 2013), and the importance of classroom-level awareness in general (e.g., Cuendet et al., 2013), the challenge that clutter and a scattered user interface pose in augmented paper applications (Cuendet & Dillenbourg, 2013), etc. The results also show that the facilitation CL is highly dependent on the teacher's prior experience (also anticipated by Feldon, 2007).

Our results across the three studies also provide a new insight about orchestration load: the fact that it seems to be correlated to the amount of "open alternatives" (i.e., the perceived uncertainty/entropy of the classroom situation). More novice teachers seemed to be especially sensitive to these high-uncertainty situations

(e.g., looking at students faces during an explanation, trying to assess their comprehension; looking at students' backs while working in the tabletops, trying to assess their progress). This need of novice teachers for classroom management support had already been mentioned in recent works like Raca & Dillenbourg (2013), and can be used as a starting point for new technologies that can ameliorate the challenge of this kind of episodes (e.g., a system that helps novice lecturers to assess the attention or comprehension of their students).

The present work, however, also presents several limitations, and the proposed method for estimating CL in facilitation of CSCL should be understood as only a first approximation. One limitation that this work shares with most research on orchestration is the limited number of participant teachers, which begs the question of the generalizability of these results: in contrast with learning in the classroom, teaching enactment is often a solitary endeavor. This problem, however, is difficult to solve, unless we resort to the sharing of datasets to help replicability and the accumulation of empirical evidence in this area. Another limitation is the cost of the mobile eye-tracking instruments themselves, and the fact that its initial calibration requires the presence of a researcher/assistant: therefore, it can be difficult to use on in-the-wild longitudinal studies. Also, we should note that the eye-tracking data analysis performed in this paper (featuring a session median cut), while more robust to classroom conditions that may vary from day to day (or hour to hour), will only capture relative load among different episodes *in the same session* (not absolute measures of load, or comparisons across sessions): a low-load episode in a difficult session might be actually more loading than a high-load one on an easy session.

This last weakness points us to the most immediate next steps in this research direction: the combination of these objective measures of CL with other complementary methods, e.g., to assess the overall load of the session using self-report questionnaires. Also, more nuanced analysis of CL could be performed by using more complex quantiles and/or different weights in the calculation of the load index. Another interesting path to follow is to attempt to separate the different components of CL, a problem that still proves difficult (Paas et al., 2003), and even more so in uncontrolled environments and complex tasks like teaching. The combination of different CL measurement techniques also has shown potential to help in this regard (DeLeeuw & Mayer, 2008). Last but not least, we aim to use this method (or its future enhancements) as part of our design-based research on the application of augmented paper in the orchestration of authentic primary school classrooms.

With this work, we add a new instrument to the CSCL researcher's toolkit to design and evaluate the material conditions of CSCL and novel proposed technologies, in authentic settings. However, this work could have implications for the design of pedagogical interventions as well: assuming equal potential for learning, are two classroom scripts equally easy to manage? In this area, considering orchestration cognitive load could help us make informed design decisions that could help drive teacher adoption of CSCL practices.

Endnotes

- (1) The interested reader (and to facilitate study replicability) can find the pre-processing, analytic and visualization scripts, as well as further analysis results (and pointers to the available raw anonymous datasets) for this and the other studies described in this paper, at https://github.com/chili-epfl/cscl2015-eyetracking-orchestration.
- (2) There might be concerns that the mere fact of using the eye-tracking device might have rendered the learning situations "un-authentic". However, the participant teachers reported "forgetting about them", and students themselves made few remarks about it in the first minutes of the lessons, and none more afterwards, until the lesson finished.

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Mixing In-Class and Online Learning: Content Meta-Analysis of Outcomes for Hybrid, Blended, and Flipped Courses

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Abstract: Over the past 15 years, courses that mix face-to-face and online instructional methods, such as blended, hybrid, and flipped courses, have gained both supporters and skeptics in higher education. Studies that compare mixed courses to face-to-face or online courses have conflicting results: some find improved learning outcomes and some find no significant differences. We contend that these conflicting results are due to inconsistent or vague definitions of hybrid, blended, and flipped. To address this problem, we use the definitions from a recently proposed taxonomy to reclassify studies in the literature. After reclassification, analysis of this literature reveals two main themes that illuminate how mixed instructional methods affect learning outcomes. Courses that use mixed methods can either reduce time in class and maintain learning outcomes or maintain time in class and improve learning outcomes.

Keywords: hybrid, blended, flipped, inverted, content meta-analysis

Introduction

Since 2000, a growing group of educators has been interested in mixing face-to-face and online instructional methods. Mixed method courses, commonly called hybrid, blended, or flipped (which is sometimes called inverted), have both face-to-face and online components. Because they employ pedagogical resources supported by both instructors and technology, they allow students to receive more instruction without substantially increasing the workload of instructors (Banerjee, 2011, U.S. Department of Education, 2010). For example, students in a traditional math course typically receive content in class (i.e., through lectures) and solve problems for homework. In contrast, students in a mixed method math course receive content before class through videos and solve problems during class with instructor feedback. Providing feedback during application activities, like problem solving, has been identified as a critical component of education (National Research Council, 2011) and a service that will keep universities relevant after all content is easily available online for free (Bok, 2006). Many instructors, however, feel that they need to lecture to ensure student understanding of course content. Mixed method courses allow instructors to provide both feedback and lectures, supporting learners when they both receive and apply content.

Much research has been conducted in the past several years to assess the effectiveness of mixed method courses, but the results of that research have been inconclusive: many mixed method courses improved learning and just as many did not. The differences between courses that improved outcomes and those that did not are unclear due to the ill-defined terms used to describe the courses that were evaluated. For example, the term "blended" has been used to describe a course in which students learn content before class and practice applying content in class (Melton, Graf, & Chopak-Foss, 2009) as well as a course in which half of the lectures are delivered in class and the other half are delivered online (Gerlich & Sollosy, 2009). The pedagogy of these courses is different, but they are classified as the same type of course.

The inconsistent definitions make comparing results, replicating experiments, implementing course design, and finding and understanding information from the literature difficult. To address this issue, Margulieux, Bujak, McCracken, and Majerich (2014) proposed a taxonomy that used pedagogically relevant dimensions to define terms. The taxonomy classified the design of courses based on the type of instruction that was delivered (either didactic exposition of content or feedback on application of content) and how that instruction was delivered (either via an instructor or via technology). The taxonomy defines a hybrid as a course that is delivered via both instructor and technology and primarily delivers one type of instruction. It differentiates between lecture hybrids in which instruction primarily delivers content and practice hybrids in which instructor and technology and feedback. The most common type of blended course, a flipped blend, delivers content via technology and provides feedback via instructor. Supplemental blends deliver content via both instructor and provides feedback via technology. We used these definitions to

reclassify studies of mixed methods courses. Based on these new classifications, the results of the studies were reinterpreted to identify themes in the literature that were previously unrecognized.

Analysis

We employed a content meta-analysis methodology. Content meta-analyses systematically aggregate information from a number of studies but use a qualitative approach instead of a quantitative approach (Jeong, Hmelo-Silver, & Yu, 2014). Given the large variations in research methodology and quantitative data sources (e.g., grades on exams, projects, or concept inventories) of the selected papers and inconsistent reporting of key measurements (e.g., sample size), a qualitative approach was more appropriate than a quantitative approach.

Paper selection

To find relevant papers, the ERIC, Proquest Education Journals, Academic Search Complete databases, and Google Scholar were queried for permutations of the terms "hybrid," "blended," "flipped," and "inverted" with the terms "class," "classroom," "course," and "learning" in the title or abstract. The title or abstract also had to include "comparison," "experiment," "evaluation," or "performance." Articles that met these criteria were considered for inclusion. If their abstracts did not mention student "outcomes," "knowledge," "achievement," or "grades," the articles were excluded. Studies also must have included a control group that was the previous (traditional) version of the course. This analysis includes only research that reported learning outcomes. Much of the research and reviews on mixed method courses have focused on student and instructor perceptions instead of learning outcomes (Ginns & Ellis, 2007), but outcomes are imperative to determine the efficacy of mixed methods. This analysis also focuses on higher education, so only studies of for-credit, higher education courses were included. Measures of learning outcomes must have been equivalent in experimental and control groups.

Reclassification of studies

The 49 selected studies (out of 163 considered studies) were reviewed to identify pedagogical components of courses. The designs of the mixed method and traditional (control) courses were coded for how instruction was delivered to students (via an instructor or via technology) and what type of instruction was delivered (exposition to content or feedback during application of content). The difference between course designs was coded for changes in delivery medium, instruction type, and time spent in class. Courses were from a range of domains and mostly from American higher education institutions

Of 17 courses that were reported as hybrid in the literature, 5 were reclassified as a type of hybrid, 10 as a type of blend, and 2 as other types of courses. Of the 11 courses that were reported as blended, 5 were reclassified as a type of hybrid, 5 as a type of blend, and 1 as another type of course. This array of reclassifications suggests that courses reported as hybrid and blended included several types of courses that differed on the fundamental features of the course. Of the 21 courses that were reported as flipped or inverted, all but 4 were reclassified as a flipped blend (including four with an additional in-class lecture component). Figure 1 summarizes the theme of results for each type of hybrid and blended course. The only type of mixed method course that consistently improved learning outcomes was the flipped blend.

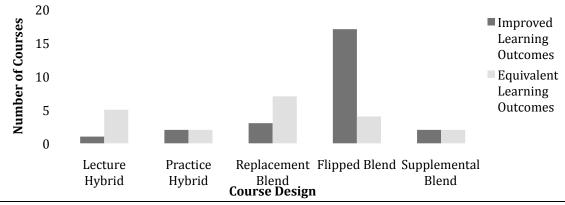


Figure 1. Mixed method courses categorized by design and split by reported learning outcomes.

Analysis of differences between mixed method and traditional courses

To explore why mixed method courses did or did not improve learning outcomes, the differences between mixed method courses and traditional courses were considered.

Delivery medium

Of mixed method courses that changed only the delivery medium (e.g., lecture hybrids and replacement blends) from the traditional courses, 79% (15 out of 19) did not report a change in learning outcomes. The four studies that reported improved learning outcomes argued that asynchronous delivery of instruction was beneficial to student learning. This argument is supported by a meta-analysis that compared face-to-face courses, which are inherently synchronous online courses performed slightly better than students in face-to-face courses, and students in face-to-face courses performed slightly better than students in synchronous online courses. They argued that asynchronous online to receive content at their own pace and to reflect more on their answers while applying that content (e.g., in discussion forums).

The effect of delivery medium was at the center of the educational media debate in the 1990s. In this debate, Clark (1994) took the point of view that media is merely a vessel that delivers information, and properties of the information and the learner are those that affect learning. Taking the opposite view, Kozma (1994) argued that media have many properties that affect learning. The prevailing view today is that different types of media have different affordances. Though some types of media are better suited for some types of learning, several types of media can be equally effective for several different types of learning (Ainsworth, 2006). Therefore, unless an instructor uses an ineffective medium for instruction, media should not have a large effect on learning outcomes.

Though online instruction generally did not improve learning, the lack of a difference in learning due to delivery medium changes is an important finding. If technology can deliver instruction with the same efficacy as instructors, then technology can be used as a resource to either supplement face-to-face instruction or reduce the amount of time students need to be in class. Possible benefits of using technology to supplement instructors include increasing the quality of instruction (by increasing the resources available to students) and the accessibility of instruction (by reducing the amount of class time required for a course). The goals of using mixed methods depend on the instructor, students, course, and institution, but course outcomes should not be negatively impacted by appropriately delivered instruction via technology.

Type of instruction

A feature of mixed method courses that made a consistent impact on learning outcomes was type of instruction. Of mixed method courses that added instruction during application of content to traditional courses, 77% (23 out of 30) reported improved learning outcomes. That percentage increases to 88% (23 out of 26) if the four courses that already had feedback during application and simply added more are not included. The majority of classes that added instruction during application and reported improved learning (17 of the 23) were flipped courses. These classes typically have recorded video lectures to be viewed before class and then application activities in class completed in small groups and with an instructor's (and sometimes teaching assistants') feedback. Only 4 of the 21 flipped courses did not report improved learning outcomes.

A range of learning theories and frameworks supports the benefits of in-class application activities. Theories based on active learning (the type of learning that requires students to play an active role in education by answering questions, problem solving, etc.) argue that applying content helps students learn more efficiently and deeply. A meta-analysis of 225 studies about active learning in STEM courses found that performance on exams and concept inventories was, on average, .47 standard deviations higher for courses that had some active learning than courses that had traditional lecture only (Freeman et al., 2014). Furthermore, in-class application activities require all (or at least most) students to participate, as opposed to in-class lectures, in which typically only highly motivated students participate (Crouch & Mazur, 2001). Moreover, Black and Wiliam (1998) argue that application activities provide opportunities for students and instructors to interact, allowing students to receive feedback on their grasp of the content and instructors to receive feedback on the efficacy of their instruction. Similarly, experiential learning frameworks are based on students applying content with an instructor present to give feedback. The central belief of experiential learning is that students learn best when they construct knowledge by integrating new content with prior knowledge, and one of the most effective ways to achieve this integration is by allowing students to direct their learning while working through application activities (Hmelo-Silver, 2004).

Feedback during application activities is important for learning. The question for mixed method courses becomes, does this type of instruction need to take place in the classroom? To address this question, the courses that added technology-mediated application were further analyzed. Of the four supplemental blends (i.e., lectures in class and technology-supported application outside of class), two of them reported learning improvements and two of them did not. The two that reported improvements asked students to use technology to practice recurrent skills (skills that are always executed in the same way), such as practicing conjugation for a

language class with vocabulary drills. The two that reported equivalent outcomes asked students to use technology to practice non-recurrent skills (skills that are executed differently depending on the application). In addition, two other courses continued application activities online that started in class (e.g., continued a discussion that started in class), and they both reported improved learning outcomes.

Based on these findings, one tentative conclusion is that technology might effectively support some application activities but not others. Jia, Chen, Ding, and Ruan (2012) argued that technology can support application activities that would be repetitive and time-consuming for an instructor to support. Technology might even be better in these cases because it typically provides feedback more quickly than instructors, leading to higher student satisfaction (Gikandi, Morrow, & Davis, 2011). If a theme can be found in these six studies, it would support Jia et al.'s (2012) argument by suggesting that technology-supported applications are more successful when the applications are repetitive, like practice drills or a continuation of an in-class activity.

For the two studies that did not find learning improvements, both asked students to solve problems (that used non-recurrent skills) with feedback exclusively from a computer program. The nature of instructional support that students received from these programs was unclear, but based on the predominately positive findings from flipped courses and the neutral findings from these courses, it is likely not equivalent to in-class support that students in flipped courses received. In a review that compared human tutoring to computer tutoring, VanLehn (2011) found that answer-based computer tutors (i.e., those that indicate only whether the final answer is correct or not) are less effective than step-based computer tutors and human tutors (i.e., those that indicate whether each step the student took is correct). This difference, VanLehn argues, is due to the granularity of feedback and scaffolding that students receive. Because students using step-based computer tutors or human tutors receive information about each step that they took in the problem solving process, they can identify and repair faulty logic or misconceptions more easily. In their 4C/ID model of complex learning, van Merrienboer, Clark, and de Croock (2002) argue that students need this type of support while learning non-recurrent skills, but not necessarily while learning recurrent skills. The technology used in these courses was likely an answer-based computer tutor and might not have provided sufficient support for non-recurrent skill building.

Time in class

Because of the increased use of technology outside of the classroom, instructors of mixed method courses commonly underestimate the amount of time students will spend on the course, resulting in a more time consuming course (i.e., "a course and a half"). Though many of the studies in this review did not directly measure time spent on the course outside of class, many did reduce the amount of time students spent in class to accommodate additional coursework outside of class. Nearly half (22) of the studies decreased time spent in class for the mixed method course, and the majority (18 courses, 82%) of these courses did not report improved learning outcomes. These results suggest that courses can reduce time spent in class without negatively impacting learning.

Of the 27 mixed method courses that did not reduce time spent in class, most (85%) reported improved learning outcomes. Though these studies did not reduce class time, approximately half of them reported efforts to keep the workload of the students in the mixed method course equal to that of the students in the traditional course. It is possible, however, that improved learning outcomes are partially caused by a greater workload. Without more research, it is difficult to speculate on the effect size of workload, but these findings suggests that time in class is valuable for learning outcomes. Whether that value comes from face-to-face interactions with the instructor, collaboration with other students, or the culture of the learning environment is much speculated upon by the educational community and in need of additional research.

How mixed methods affect learning

Regardless of instructional method, students generally get the same two types of instruction: course content and application activities. For example, to learn about a law in a physics course, students generally get a lecture and a reading about that law and complete homework problems to ensure that they can apply their knowledge. To learn about an historical event in a history course, students generally get a lecture and a reading about that event and discuss or write about its impact to ensure they can apply their knowledge. Given these general constants, this review analyzed how mixed methods of instruction affected learning. The results suggest that, in general, mixed method courses can maintain learning outcomes for a course while reducing time in class, or they can maintain time in class and improve learning outcomes.

This review found that adding feedback during application of content improved learning outcomes. Courses that improved learning outcomes did not typically add additional application activities, they added only the feedback that students received while completing the application activities. This finding suggests that giving students application activities is more effective when feedback is provided. In addition, because these courses used multiple methods of instruction, they were not forced to reduce the amount of content covered in didactic lectures when they added feedback.

A common approach to teaching, especially in STEM domains, is to provide only didactic instruction during class and to assign application activities to be completed outside of class. This approach, however, does not typically provide the structure and support that many students need to be most successful when they start applying content (Baeten et al., 2013). Alternatively, experiential learning (e.g., problem-based learning) and constructivism focus on providing feedback during application activities and charging students with identifying and learning the content that they need to know (even if that involves asking the instructor or TA). Proponents of experiential and constructivist learning argue that students have different backgrounds and bring different prior knowledge to the classroom; therefore, the most effective way to help students build new knowledge is to guide them through the process of gathering information and constructing that knowledge rather than providing information based on how the instructor organizes it (Baeten et al., 2013; Hmelo-Silver, 2004; Jonassen, 1999). Research on experiential and constructivist learning methods, however, do not consistently support this argument (e.g., Baeten et al., 2013; Cennamo et al., 2011; Hmelo-Silver, 2004), suggesting that providing instruction through only feedback is not necessarily better than providing instruction through only lectures.

Kirschner, Sweller, and Clark (2006) argue that this inconsistent success of experiential learning is due to high cognitive load of students during application activities. More specifically, they argue that if students are trying to organize new information at the same time that they are attempting to apply that information, then the cognitive load associated with the task is too high to promote learning. Cognitive load can be further taxed when students work in groups, especially if they are expected to provide feedback to their peers (Ching & Hsu, 2013). Instead of starting with application of information, Kirschner et al. (2006) suggest that students should be taught a basic level of information and how to organize it to provide necessary cognitive structure for a topic before starting application activities. This suggestion aligns with Maki and Maki's (2002) findings that unstructured courses, whether they were face-to-face or online, were less successful than structured courses.

Because students in online learning environments do not necessarily have immediate access to an instructor and therefore cannot ask questions, structure in online learning environments is perhaps more important than in face-to-face learning environments. For example, Xie and Bradshaw (2014) found that, for successful online discussions, well-defined tasks and moderation provided necessary structure. Perhaps for online problem solving tasks, the same type of structure is necessary. We found that courses that used software to facilitate problem solving were no more effective than unaided problem solving perhaps because the software did not provide appropriate (in terms of type, quantity, or quality) structure, feedback, or scaffolding during problem solving. As VanLehn (2011) argued, when student receive feedback for each problem solving step that they take, they can more effectively identify incorrect thinking and fix it. In addition, scaffolding is a method used to provide extra structure and support while students are learning to complete application activities, especially with problem solving. It is intended to allow novices to successfully complete activities of which they would otherwise not be capable. For example, if a problem solution involved five steps, a scaffolded problem might provide two of those steps for the learner. As the student becomes better at solving problems, the scaffolding is incrementally removed until learners achieve the solutions independently.

Scaffolding accelerates learning by helping students to complete activities that they would otherwise not be able to do, such as complex or authentic tasks (Hmelo & Guzdial, 1996). Though scaffolding is typically pre-prescribed and static, it can be highly effective in a more dynamic role because the level of support needed differs among learners and providing too little or too much support inhibits learning (Pea, 2004), but few technologies are capable of dynamic scaffolding. Perhaps one of the reasons flipped blends improved learning outcomes is because, during application activities, instructors can provide dynamic scaffolding that gives more support when necessary. If the instructor is readily available to help students, then more challenging application activities (e.g., in terms of transfer or complexity) could be assigned than if students were given those activities to be completed independently. These classes also provided didactic lectures to help students learn and organize content, but the mixed methods of the course allowed this instruction to be delivered at the convenience of the student and did not take class time.

In summary, this review suggests that mixed methods can help educators achieve two main goals. If instructors are trying to improve the learning outcomes of their course, then mixed methods can help by allowing students to receive instruction both inside and outside of class. If instructors are trying to reduce the resources needed to teach a course, then mixed methods can help by providing instruction through technology and reducing time spent in class. By better understanding the potential of mixed method courses, instructors can better employ these methods to fulfill the needs of their students.

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Dragging as a Referential Resource for Mathematical Meaning Making in a Collaborative Dynamic-Geometry Environment

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Abstract: This paper focuses on the referential roles played by dragging moves on dynamicgeometry representations in a collaborative-geometry problem-solving context. Through an interaction analysis of chat excerpts where dragging is used by a team of students to explore the geometric properties of a given polygon, the paper investigates the role of dragging on the facilitation of joint mathematical meaning making online. Our qualitative findings suggest that the indexical properties of the dynamic constructions are specified and recalibrated through the coordination of dragging actions with textual chat, where the two types of actions mutually elaborate each other.

Keywords: dynamic geometry, meaning making, referential practices

Introduction

Dynamic Geometry Systems (DGS) such as GeoGebra, Geometer's Sketchpad and Cabri offer unique affordances for exploring and making sense of geometry (Arzarello et al., 2002; Hölzl, 1996). The visual interface provided by such micro-worlds allows students to construct geometric objects by using elements of Euclidean Geometry such as points, lines and circles through a digital analog of compass and straight-edge constructions. More importantly, the object-oriented design of these micro-worlds allows students to dynamically act on these constructions by dragging their constitutive elements, which helps them to interactively explore the implications of the dependencies within those constructions (Stahl, 2013). By developing increasingly more purposeful dragging strategies, students may notice how a family of Euclidean constructions relate to each other and whether specific invariants are present in that family of figures (Arzarello et al., 2002). Therefore, such dynamic representations can be instrumental in helping students develop a deeper understanding of geometry by making otherwise obscure ideas/theorems in geometry more accessible. The possibility of testing an invariant across a continuum of cases can also help students to develop intuitions for generalizations that go beyond the particular construction view at hand (Leung, 2008).

The nature of the dragging actions through which geometric constructions are manipulated and explored, and their role in facilitating students' understanding of geometry concepts have been investigated by several studies in the math-education literature (Arzarello et al., 2002; Baccaglini-Frank & Mariotti, 2010; Leung, 2008; Lopez-Real & Leung, 2006; Hölzl, 1996). In particular, Arzarello et al. (2002, p.67) proposed a hierarchy of dragging modalities that distinguish wandering dragging (randomly moving basic points to fish for interesting configurations or regularities in the dynamic diagram), bounded dragging (moving a restricted point), guided dragging (moves aimed to give the dynamic drawing a particular shape), dummy locus dragging (moves that reveal that a point is restricted to move on a specific path), *line dragging* (drawing new points along a line in order to keep the regularity of the figure), *linked dragging* (linking a point to an object and moving it onto that object) and the dragging test (moves aimed to test if a particular property of the current shape is preserved). These dragging actions are employed by students at different stages of their problem-solving activity, which provide insights into their reasoning with dynamic representations. In particular, wandering and guided dragging are employed during exploration/discovery phases, dummy locus dragging often hints at the construction of a conjecture, and the dragging test is often used to validate/justify conjectures. Therefore, dragging is treated as a key process facilitating the development of cognitive structures that bridge perceptual observations with formal accounts of deductive reasoning in geometry (Arzarello et al., 2002).

The focus of the studies reviewed thus far has been on the individual learner developing a sense of understanding through his/her interaction with dynamic representations. However, acting on these dynamic resources also has a social significance, which changes the problem context not only for the actor himself but also for collaborators witnessing those actions. At the individual unit of analysis, the meaning-making role of the dragging actions may be difficult to investigate from the actions themselves or think-aloud protocols. In a collaborative problem-solving situation, such actions become resources for joint meaning making, which are acted upon, referred to, reasoned with, and questioned in collaborative discourse (Stahl, 2009). Therefore, such collaborative activities present a perspicuous setting for researchers to explore how actions with and around dynamic geometry objects facilitate the development of shared mathematical understanding.

This paper focuses on the referential roles played by dragging moves on dynamic-geometry representations in a collaborative geometry problem-solving context. Our interest is motivated by recent CSCL studies that treat collaborative problem solving as "discovery work," in which collaborators work out the indexical details of their joint situation by calibrating and recalibrating references to relevant constituent elements of their shared task and its evolving solution (Zemel & Koschmann, 2013; Koschmann & Zemel, 2011). Indexical expressions refer to those linguistic resources whose sense depends on the context of the utterance. Through a process of calibrating and recalibrating references to an evolving space of persistently available diagrams, participants increasingly specify what those representations mean for them as part of an evolving solution account. Referring expressions initially function as a place holder for what is currently not known, which gets specified further (i.e., thingified) as subsequent actions and references modify their sense in interaction (Koschmann & Zemel, 2011). We argue that dragging actions have a similar referential role, which facilitates the discovery process with dynamic representations in geometry. Through an interaction analysis (Jordan & Henderson, 1995) of excerpts where dragging is used to explore the geometric properties of a given polygon, we identify the role of dragging on the facilitation of joint mathematical meaning making by studying how the dragging is used to increasingly specify the indexical properties of the dynamic construction.

Methods and data

The excerpts analyzed in this paper are obtained from the Virtual Math Teams (VMT) Spring Fest organized by the Math Forum in 2013. The analyzed chat session is part of a broader curriculum-development activity including the use of dynamic geometry in math classes supported through online collaborative-learning activities in the VMT system. The team consisted of Fruitloops, Cornflakes and Cheerios who are female students about 14 years old, who have not yet studied geometry. This team completed seven hour-long chat sessions of dynamic-geometry tasks in the VMT environment before they met for the session from which the excerpts were obtained. In this session, the team was given a set of 21 different quadrilaterals and was asked to (a) identify their dependencies, and (b) tell how each of them was constructed. The task description suggests participants drag the vertices of each quadrilateral to see what is special about each one. The GeoGebra application also hints at the presence of dependencies/constraints by shading vertices that are dependent on other points. Excerpts from this chat session were subjected to interaction analysis to investigate the referential roles fulfilled by dragging actions.

During the session, participants interacted through the VMT environment (Stahl, 2009), which provides a chat interface with an integrated electronic drawing area with collaborative dynamic-geometry drawing capabilities. The dynamic drawing area is based on GeoGebra, a popular dynamic-geometry application. The VMT environment allows a group of users to co-construct and discuss shared dynamic-geometry objects online. Access to the drawing area is managed through a turn-taking mechanism, which allows only one user at a time to construct or manipulate dynamic objects. The VMT system also supports researchers by providing replayable logs of these sessions for analysis, allowing step-by-step walkthroughs of drawing and typing actions that took place during the online student sessions. The excerpts discussed in this paper involve manipulation of dynamic objects through dragging moves—which is challenging to present in a text document. For that reason, screenshots that capture intermediary states of the dragging actions are provided to complement the chat logs.

Analysis

Excerpt 1

The excerpt starts when the team decides to move on to polygon #2 (i.e., EFGH). Before exploring polygon #2, the team took turns to explore polygon #1 (i.e., ABCD) by dragging each of its four vertices; they quickly concluded that none of the vertices had any dependencies (i.e., they are free points). In line 1, Cornflakes announces that she will explore polygon EFGH, and then she takes control of the drawing area. Cornflakes first drags vertex F. The series of screenshots displayed in Figure 1 shows how polygon #2 changes while Cornflakes is dragging point F. Cornflakes drags point F up, left, down and then right, tracing almost a complete circle around point E in a counter-clockwise direction. Note that points E and H are unaffected by this drag, but point G is apparently moving as F is dragged.

- 1. cornflakes (3:20:26): ill do polygon efgh
- 2. cornflakes (3:20:33): takes control of the drawing area
- 3. cheerios (3:20:37): just say the number its easier

- 4. cornflakes (3:20:40-3:20:50): drags points F (Figure 1), H, D, E (Figure 2) and G (drags on H, D, and G were not visualized in the figures. D is part of another polygon the team worked on prior to EFGH, which is not displayed).
- 5. cornflakes (3:20:52): releases control of the drawing area
- 6. cornflakes (3:21:17): okasy polygon 2 has all points moving except point g
- 7. cornflakes (3:21:28): and point g is also a different color
- 8. **cheerios** (3:21:40): do u think it is restricted
- 9. cheerios (3:21:44): or constrained
- 10. **fruitloops** (3:21:49):i feel like poly 1 and poly 2 are almost exactly the same except that poly 2 had one point that is a lighter shade
- 11. fruitloops (3:22:04): can i try moving it?
- 12. cornflakes (3:22:17): sure
- 13. fruitloops (3:22:25): and @ cheerios, i dont know for sure

Figure 1. Cornflakes drags vertex F counter-clockwise around point E. Each screen shot corresponds to different stages of the polygon as F is dragged. The dashed lines are provided to aid the interpretation of the dynamic changes enacted by the dragging action. The dashed line over E, which was not affected by the drag, is provided as an anchor to aid the visual comparison between stages. Arrows show the direction of the drag.

Next, Cornflakes drags vertex H up and down. Then she begins to drag point E. The steps of this dragging action are displayed in Figure 2 below. Point E is slightly moved to up-right and then to bottom-left, which did not seem to affect any other vertex, except very minor shifts on G's position. Finally, Cornflakes drags point G. Point G is moved up-left and then down-right slightly as a consequence of this dragging action. None of the other vertices seem to be affected.

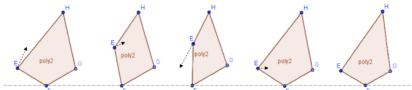


Figure 2. Cornflakes drags point E. Black arrows indicate the direction of the next drag.

After dragging point G, Cornflakes posts two chat messages (lines 6 & 7), announcing that "polygon 2 has all points moving except point g", and notes that point G is also marked with a different color. Cornflakes' account marks G as different from other points based on the claim that all points can move except G, even though she has explicitly moved point G during her last drag. The way she formulates her observations from her drags suggests that she is oriented towards whether a point can be freely moved or not. Cheerios responds to Cornflakes in line 8 by asking if she thinks "it" is restricted or constrained. The indexical "it" can be read as a reference to point G, since this point was the most salient object mentioned in Cornflake's chat messages besides polygon #2. By explicitly mentioning the terms "restricted" and "constrained," Cheerios invokes relevant terminology that encodes specific distinctions among the kinds of points one can make in GeoGebra. Hence, Cheerios' message can be read as an implicit assessment of Cornflake's account in terms of its descriptive adequacy, as well as an attempt to orient Cornflake's proposal towards a more formal account. So, Cheerios' statements can be seen as a *recalibration* move. Both terms seem to index a kind of limitation in the movement of a point based on their dependencies on other points, but the specific distinction encoded in this terminology has not been explicitly specified yet.

Next, Fruitloops posts the message she has been typing while Cheerios' messages appeared in chat, which states that polygon #1 and polygon #2 are almost the same except for the point with the lighter shade (line

10). Fruitloops' account seems to be informed by her observation of Cornflakes' prior dragging moves, and makes a visual reference to the color-coding of each vertex. She then requests the team's permission to try moving the polygon on her own in line 11. In line 12, Fruitloops responds to the question raised by Cheerios, that she is not sure about the restricted/constrained distinction.

Overall, in excerpt 1, the team seems to be oriented towards how the points can be moved around based on the witnessed dragging actions enacted by Cornflakes. The team does not mention more specific dependencies among the vertices, as the drags are rather minimal and hence have not yet hinted at the more complicated structure underlying polygon #2's construction. The team members seem to be oriented towards visually salient features of polygon #2, such as having a point G that is lighter in shade. Based on what is revealed by the drags performed by Cornflakes, the team seems to endorse the interpretation that polygon #2 is very similar to polygon #1 except for the vertex with the light blue shade. Cheerios contributes to the discussion by making the concepts "constrained" and "restricted" relevant to ongoing interaction as a means to categorize vertices. Yet, it is still not clear how these terms should be applied to the problem at hand.

Excerpt 2

Fruitloops takes control of the GeoGebra area and begins to manipulate the shared dynamic drawing (line 15). Figure 3 shows a chronologically ordered series of screen shots from her dragging of point G. The dashed reference lines crossing over point E, which remained stationary while Fruitloops was dragging point G, are provided to aid the comparison of different stages. Fruitloops' drag gradually moves point G in a circular motion, first in a clockwise and then in a counter-clockwise direction, which is followed by several full circles in both directions. As Fruitloops is performing the drag on G, she seems to gradually notice the path that point G is constrained to, which is evidenced in the way she moves the vertex back and forth repeatedly in clockwise and counter-clockwise directions in this episode (Figure 3). Meanwhile, Cheerios requests permission to access the drawing area, which is acknowledged by Cornflakes. However, Fruitloops holds onto her turn in the drawing area, while she is typing what will appear in line 18, which states, "so point g only moves in like a circular motion around point f." Fruitloops' account is a reflection on or noticing of what has been discovered in the dragging. The message specifies the relationship she notices between points G and F without making any reference to more technical terms such as restrictions or constraints, but using only colloquial terms or descriptions. In the next line, Cornflakes agrees. This is followed by further drags of point G around F by Fruitloops, which seem to complement her exposition in line 18 with an enactment of the verbally described movement pattern. These drags also simultaneously verify the proposed relationship, which recalibrates the status of vertex G for the group in this context.

- 14. fruitloops (3:22:42): takes control of the drawing area
- 15. fruitloops (3:23:04): drags Point G (Figure 3)
- 16. cheerios (3:23:18): ok can i try
- 17. cornflakes (3:23:22): sure
- 18. fruitloops (3:23:23): so point g only moves in like a circular motion around point f
- 19. cornflakes (3:23:35): @fruitloops yea
- 20. fruitloops (3:23:50): drags Point G

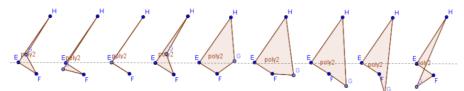


Figure 3. Chronologically ordered screenshots taken while Fruitloops is dragging vertex G.

In this episode, through her rigorous drags of vertex G, Fruitloops uncovers an important property of polygon #2: that vertex G always follows a specific circular path around point F. As soon as she gains control of the drawing area, Fruitloops starts dragging the point with the lighter shade. Fruitloops' initial drags on G seem rather exploratory, which gradually becomes more orderly and purposeful as she notices the constraint imposed on G. While Fruitloops is communicating this noticing to her teammates, she coordinates her actions across both chat and drawing areas in such a way that her verbal description in chat can be read in relation to her ongoing enactment on the shared drawing. In short, the sequential organization of Fruitloops' actions across both

interaction spaces made her point witnessable by her teammates. This instance highlights another important aspect of dragging in dynamic geometry. The progression of drags from exploratory trials to purposeful demonstrations/tests serves both as a public display of an evolving understanding and as a resource for communicating abstract visuo-spatial relationships that may be difficult to articulate in text. Thus, drags also have a social role in this context, as demonstrable actions embodying specific conjectures about dependencies among geometric objects.

Excerpt 3:

Following Fruitloops' demonstration, Cheerios asks about the difference between the terms "constrained" and "restricted" in line 23. Cornflakes states that "constrained is limited function," which provides some specificity for one of the terms. In the meantime, Fruitloops continues to drag vertices of polygon #2. She first drags point H slightly to the bottom. No other point seems to be affected by this move. Next, she begins to drag point E (Figure 4). Point E is gradually moved away and towards point F, which simultaneously moves point G out and towards point F. Fruitloops carefully and slowly drags E around F, which suggests that she is oriented towards the relationship among E, G and F triggered by the dragging action on E.

- 21. fruitloops (3:24:09): drags Point H (Figure 4)
- 22. fruitloops (3:24:15): drags Point E (Figure 4)
- 23. cheerios (3:24:16): what si the difference between constrained and restricted
- 24. fruitloops (3:24:17): drags Point G (Figure 4)
- 25. fruitloops (3:24:21): drags Point E (Figure 4)
- 26. cheerios (3:24:24): is*
- 27. cornflakes (3:24:41): constrained is limited function
- 28. fruitloops (3:24:46): also when you move e, g moves away or closer to f
- 29. fruitloops (3:25:08): so i think g it definitly constrained
- 30. fruitloops (3:25:12): drags Point H
- 31. cornflakes (3:25:13): yes
- 32. cornflakes (3:25:19): i think that too
- 33. cheerios (3:25:25): why though
- 34. fruitloops (3:25:31): drags Point,F
- 35. **fruitloops** (3:25:59): and g moves whenever you move point e and f but it doesnt move when you move h
- 36. cheerios (3:26:20): okay
- 37. *fruitloops* (3:26:31): releases control of the drawing area

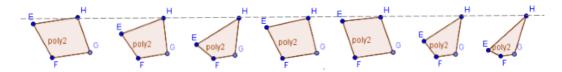


Figure 4. Fruitloops drags vertex E, first towards F, then away from F and then towards it again.

Fruitloops then posts in line 28 that "also when you move e, g moves away or closer to f." This can be read as a verbalization of the recent drag on E, which demonstrates the relationship among points E, G and F, where dragging E affects the position of G with respect to F. Similar to the previous instances, the verbal announcement of the noticed properties immediately follow the dragging actions. In line 29, Fruitloops elaborates on the prior message by proposing that G must be constrained. This statement also responds to the ongoing discussion of the distinction between constraints and restrictions, by proposing point G as an instance of a constrained object. In other words, the posting indexes G as a particular instance of a constrained point. In lines 31 and 32, Cornflakes concurs with Fruitloops' observation. In line 33 Cheerios posts a message wondering why the proposed relationship holds, which problematizes for the whole team the underlying cause of the relationship proposed by Fruitloops. In line 35, Fruitloops summarizes her observations after performing

another drag on F. She states that point G moves whenever points E and F are moved, but G does not move when H is moved.

In this episode, Fruitloops identifies additional key relationships among points E, F, G and H through her systematic dragging of these points. She is oriented toward observing how each point is influenced by her drags on other points. Through initially explorative and progressively deliberate drags, Fruitloops notices that G's position is influenced by moving E or F, but not H. However, her statements do not specify the nature of those relationships in terms of concepts such as lengths or angles yet. The verbal accounts are primarily characterizations of visual effects triggered by drags of different points. Based on the relationships identified between E, F and G, Fruitloops proposes that G must be constrained, which provides further specificity to (i.e., a recalibration of) what is referred to by the term "constraint" by proposing G as an exemplar (lines 28, 29).

Excerpt 4

In line 38 Fruitloops takes up the prior discussion of the distinction between constraint and restriction. Fruitloops suggests that G is constrained because it can be moved, but the function is limited (i.e., limited to move on a circle around F). Then Fruitloops posts a question asking for the definition of "dependant" (sic) in line 40. This concept is mentioned in the task description, which asks the team to identify the dependencies in each polygon. About a minute later, a chat message from Cheerios appears, stating the need for the other line or point: otherwise "it wont work." In line 43, Cornflakes agrees and states that some points depend on each other. The definitions are rather implicit and ambiguous at this point, but the concept of dependence gradually attains its meaning as a kind of connection between two or more objects in this exchange.

- 38. **fruitloops** (3:26:42): @ cheerios. i think its constrained because it moves but the function is limited
- 39. cheerios (3:27:36): oh i see
- 40. fruitloops (3:27:37): what is the definition of dependant
- 41. cheerios (3:28:52): u need the other line or point otherwise it wont work
- 42. fruitloops (3:28:54): do you guys have any idea of how this was made?
- 43. cornflakes (3:29:15): yeah some points are dependent on others
- 44. **cornflakes** (3:29:43): maybe some invisible circles and the shapes could be dependent on thos circles
- 45. cheerios (3:30:02): yea maybe like the triangles
- 46. fruitloops (3:30:20): maybe because point g only moves in a circular motion around point f
- 47. cornflakes (3:30:35): but why?
- 48. fruitloops (3:30:55): i think it has to do with how it was constructed
- 49. cheerios (3:31:03): i agree
- 50. cornflakes (3:31:29): YES
- 51. **fruitloops** (3:31:44): cause eremember how before in the other topic we would sometimes use circles to construct stuff and then hide the circles? well maybe this quad was made using a circle
- 52. cornflakes (3:31:58): yeah and one of the points was on the circle
- 53. **cheerios** (3:32:38): yeah that makes sense remember when we made the triangle the same thing happened
- 54. cornflakes (3:32:43): yes
- 55. fruitloops (3:33:10): but i dont really know how it could have been made?
- 56. fruitloops (3:33:48): releases control of the drawing area
- 57. cheerios (3:34:14): maybe they used another shape instead of circles
- 58. fruitloops (3:34:17): do you thinkk point e is the same distance away from f as g?
- 59. fruitloops (3:34:25): takes control of the drawing area
- 60. fruitloops (3:34:26-3:35:02): drags Point G (Figure 5)

In line 42, Fruitloops asks the team if they have any idea how the polygon was made. In line 44, Cornflakes proposes that there may be invisible circles accounting for the dependencies they have uncovered. In line 45, Cheerios agrees and states that this situation is "like triangles." Cheerios seems to be referring to the team's past constructions during previous sessions, where they used circles to make equilateral and inscribed triangles. In line 46, Fruitloops endorses the possibility of a hidden circle, based on the observation that G is only moving in circles around point F. In line 51, Fruitloops elaborates further by reminding other members about a past exercise where they used a circle as part of a larger construction and then hid it from view by making it invisible in GeoGebra. In line 57, Cheerios proposes the possibility that the point may even be constrained to an object other than a circle.

In line 58, Fruitloops solicits other members' assessment about the observations that points E and G are equally distant from point F. Next, she drags point G on the GeoGebra board, making circles around point F. Snapshots from Fruitloops' dragging actions are given in Figure 5. Fruitloops slows down when point G gets near point E, and drags it back and forth as the two points coincide with each other. This drag seems to explore the possibility that EF and FG have the same length. This is the first instance where a group member mentioned distance as a way to characterize a dependency among a set of points.

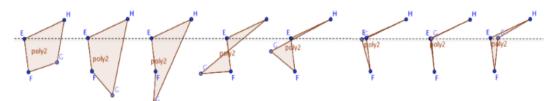


Figure 5. Fruitloops' drag on vertex G. G is seen as moving in a circle around F. Fruitloops slows down when G is about to move near vertex E.

In this episode, the team starts to reflect on the relationships uncovered between the points, and the terminology that should be used to characterize those relationships. The team begins to develop conjectures about possible ways polygon #2 might have been constructed. At this time, they relate the observed behavior to their prior experiences using circles in earlier sessions. The team seems to agree on the idea/conjecture that at least G would be constrained on such a circle. The notion of *dependence* makes its first appearance in the chat, gradually becoming a resource for describing how the polygon might have been constructed. In this episode, the team makes another key observation regarding the underlying structure of polygon #2: that the edges EF and FG have the same length. Fruitloops' drags of point E around F led her to realize that her drags influence the length of EF and FG in similar ways, where E and G can even be collapsed onto the same point.

Towards the end of their discussion of polygon #2, the team discusses how the dependencies they had discovered could be implemented in GeoGebra. The possibility of using an invisible circle for constraining G and the use of the compass tool to define two line segments of the same length are mentioned as possible steps in the construction. The team also discusses the order of the construction steps that might have been used to produce polygon #2. The proposed steps of the construction can be considered as an informal proof account, explaining why the polygon has the discovered properties. However, the team disagrees about which point would be plotted first, and cannot account for the joint relationship between points E, F and G, which precludes them from proceeding further in their joint inquiry.

Discussion

Previous literature characterizing dragging moves has primarily focused on how an *individual* learner's cognitive processes are shaped through interaction with dynamic representations, without emphasizing the social and practical significance of such actions. In this paper, we underlined the social-interactional implications of dragging actions in a *collaborative* CSCL problem-solving context. The excerpts analyzed in this paper present a detailed view of the lived work of joint reasoning performed by a team of students while they were working together to discover the geometric properties of a given dynamic polygon. The team went through a sequence of sense-making steps, including dragging, noticing, stating in chat, bridging to past meaningful experiences of intersubjective shared understanding, and using technical terms like dependency. Our analysis of the excerpts suggest that through an interactive process of *calibrating and recalibrating their indexical references* (Zemel & Koschmann, 2013) to the evolving visual configurations witnessed during different dragging performances, the team members were able to collectively notice several key dependencies among constituent elements, describe them in colloquial/semi-formal terms and produce conjectures for the underlying causes of those dependencies.

The progression of dragging performances from exploratory trials to purposeful demonstrations serves both as a public display of an evolving understanding, and as a resource for noticing and communicating abstract visuo-spatial relationships that may be difficult to describe and follow in textual communication. In the excerpts analyzed above, the availability of the intermediary stages of dragging actions made the reasoning that goes with the unfolding dragging activity witnessable by the group. The witnessed unfolding of visual changes served as an indexical ground which (a) gave sense to subsequent utterances that refer to the noticed regularities, and (b) provided further specificity to technical terms that distinguish relevant geometric relationships such as constraints and dependencies by enacting them in the dynamic figure. Moreover, the emerging purposefulness of the drags was made evident with verbal glosses following an episode of dragging, which accounted for what was there to be noticed. Hence, actions in both interaction spaces mutually elaborate each other, where (a) drags highlight key relationships and eliminate the need to verbalize every complex detail, while (b) verbal accounts direct others' attention to relevant parts of the figure where the regularities can be located.

The analyzed excerpts also suggest that not all drags are equally effective for noticing key geometric properties. This point is supported by a comparison of the dragging performances of Cornflakes and Fruitloops, and the subsequent proposals the team members had made in the discussion following those drags. Initial drags by Cornflakes led to the conjecture that polygon #2 is very similar to #1 (whose vertices had no dependencies), except for the vertex that was marked with a different color. Only after Fruitloops took over and performed more strategic drags, did the team realize that there was more to the underlying geometric structure of polygon #2. In particular, the team noticed the following regularities: (a) G moves around F in a circle and when G is moved no other vertex moves, (b) when H is moved, no other vertex moves, (c) G moves when F is moved, (d) G moves when E is moved, and (f) E and G are always equidistant from F.

The analysis of the team's work in dragging its figures shows how collaborative learning about the nature of geometric dependencies develops gradually through hands-on exploration guided by challenging tasks in a computer-supported environment. In the remaining part of their chat session, which is not covered in the above excerpts, the team members continued to explore similar polygons by taking turns dragging. The dragging strategies developed in the excerpts above were appropriated by other members during those explorations. This exemplifies the gradual transformation of one member's public display of dragging-mediated reasoning into a shared practice of geometric reasoning for the team. Through calibration and recalibration of indexical references that refer to the discovered properties of the shared dynamic drawing, team members gradually made sense of key geometry concepts as they were enacted by dragging actions on shared figures. The affordances of the VMT environment for making the results of intermediary stages of drags available for all participants and the way participants coordinated such actions with their chat messages were consequential for collaborative meaning making online. For this reason, a key design requirement to support collaborative learning in CSCL settings should be the inclusion of mechanisms that help participants effectively coordinate representational affordances, especially in contexts like geometry, where diagrams and concepts need to be closely aligned with each other. Likewise, an important part of CSCL methodology should include the analysis of discourse and actions as referential components of intersubjective meaning making.

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What Kind of World Do You Want to Live In? Positive Interdependence and Collaborative Processes in the Tangible Tabletop Land-Use Planning Game Youtopia

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Abstract: Twenty pairs of 5th grade children used a tangible tabletop sustainability game to create a world they would want to live in to share with the rest of the class. Half of the pairs were assigned particular roles with associated game controls (positive interdependence condition) while the other half were not (control condition). Results showed that pairs in the assigned roles/controls condition gave more in-depth explanations to their partners about what they wanted to do in the game, but did not negotiate with each other more frequently than control pairs. They also had fewer but longer instances of jointly resolved conflict. Contrary to some previous findings, all pairs in both conditions were found to work together (rather than in parallel / competitively) the entire time. The general finding is a somewhat limited, but consistent, positive effect of the assigned roles/tools manipulation on collaborative processes.

Keywords: Tangible systems, emergent dialogue, student roles, positive interdependence

Collaborative learning with interactive tabletops

Interactive tabletops are horizontally oriented digital surfaces that allow for direct physical interaction by users (Higgins et al., 2011). They have been highlighted as a technology particularly suited to supporting collaborative learning interactions as they are designed for more than one user, hands-on activities and multiple modes of communication (Dillenbourg & Evans, 2011). Specifically, they have been suggested to have particular affordances for facilitating joint attention and creating a shared transaction space for reference, negotiation, and action (Fernaeus & Tholander, 2006). Of course, opportunities for collaboration aren't always taken up by learners and other interaction patterns are possible such as domination by one child, independent parallel play, and competition (Marshall et al., 2009). Thus two central challenges in designing interactive tabletop applications for collaborative learning are finding ways to distribute control across a group and getting group members to engage with each other constructively (Higgins et al., 2011). One way to do this is by structuring positive interdependence into the activity design in technological and/or social ways (Dillenbourg & Evans, 2011). There are many CSCL scripts designed towards this end such as assignment of roles, distribution of information, or designation of tools to particular learners (Järvelä et al., 2004). The aim of creating positive interdependence is to encourage learners to work together (as opposed to independently, in parallel or divideand-conquer mode), animate greater negotiation of decisions taken as part of the collaborative task, and foster the resolution of conflict jointly (rather than via unilateral action).

Positive interdependence and tangibles

An important characteristic of interactive tabletops that distinguishes them from many CSCL technologies is that they support co-located face-to-face synchronous collaboration (Dillenbourg & Evans, 2011). This allows for the integration of tangibles: digitally augmented physical objects that are recognized by and can affect / be affected by the tabletop system (Ullmer & Ishii, 2000). Tangibles offer particular affordances for creating positive interdependence as they allow for the physical embodiment of distributed control, tapping into social norms around object ownership and use (Speelpenning et al, 2011). Such technological interdependence can be employed on its own (e.g. using colors to designate tangram pieces for use by different group members; Dillenbourg & Evans, 2011) or in concert with social interdependence (i.e. tools are distributed in alignment with particular duties). The latter strategy is particularly attractive as a way to address the challenge of getting learners to actually adopt the distinct rights and responsibilities of the role they are assigned (Wise et al., 2012).

Previously we have described the design of Youtopia, a tangible and multi-touch tabletop activity about sustainable land-use planning (Antle et al., 2013). The game's design includes co-dependent access points where more than one input action must be taken sequentially in order to create a successful system response. This aim of this design strategy is to encourage exploration of the game space and the content relations about sustainable land-use embedded within it (Fan et al., 2014). In this work we investigate whether adding scripted roles with

associated tools (social/technological interdependence) to the existing contingencies of tangible use (described below) affects the quantity and quality of collaboration processes. Notably, we do so in a study of children in an authentic school environment, addressing recent critiques that interactive tabletop research has been overly focused on tool development rather than in-vivo studies of collaborative learning (Higgins et al., 2011).

The Youtopia system

Youtopia is a hybrid tangible and multi-touch tabletop application about sustainable land-use planning. The activity was designed for pairs of elementary school children and aligned with the learning objectives for environmental and sustainability topics outlined in the B.C. Prescribed Learning Outcomes (Grade 5) and the U.S. National Science Education Standards (K-4). Using Youtopia, children have the opportunity to design their own world, exploring how different land-use decisions affect the amount of food, housing and energy provided to the population; and the impact these decisions have on the level of pollution in the environment. Following the principles of Emergent Design (Antle et al., 2014), our interaction goals were for children to explore the relationships between different land-use decisions, see their effects on the world, discuss the inherent tradeoffs with their partner, and through this make informed decisions to create a world they would want to live in. To foster the need to explore relationships and discuss trade-offs, the activity was calibrated to make it difficult/impossible (depending on the game mode) to satisfy human needs without some pollution.

Children begin with one of four digital maps of an undeveloped valley with different types of terrain: mountains, grasslands, forest and a river. The primary method of interaction with the tabletop is through two kinds of physical stamps that children use to designate different land-use types on the map (see Figure 1a): natural resource stamps (indicated with a tree icon); and human development stamps (indicated with a wrench icon) [see Table 1]. Each stamp also has a picture and a label describing the specific land-use type, and color is used to indicate land-uses that relate to the same human need (see Figure 1b). In this way children are supported in seeing two kinds of relationships between land-uses: first, which ones are used to meet the same human need (e.g. energy, food, housing – coded by color); and second, the interrelations of natural resources and human developments within a color category (e.g. a coal mine (tree) is a direct use of a natural resource, while a coal plant (wrench) is human development based on that resource; both are required to produce coal-based energy).

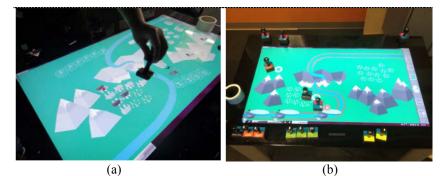


Figure 1. (a) Using a stamp to designate a land-use (b) Colored tags identify groups of related stamps

Land-use types have predefined relationships to each other and to the terrain designed to reflect real world relations (see Table 1). For example, a farm can only be built on grasslands (not on a mountain) and requires irrigation connecting it to a water source (the river). Thus different inputs to the system are codependent: while each stamp is used individually, to successfully build anything requires two or more stamps placed in sequence. Children are able to discover the underlying logic of the system in several ways. If a child stamps a 'legal' land-use (in an allowed location; required resources are met), a digital version of the land-use picture on the stamp appears on the map. If a child stamps a land-use that doesn't meet these conditions, an explanation tab focused on describing land-use relationships (e.g. "Houses need lumber from the forest to be constructed") will appear and can be enlarged and rotated (Figure 2a). When a land-use is successfully placed, any resources it requires are greyed out so that children can see the effects of using land in this way and what resources are still available. Children can also learn about how each of the land-use types work using the info ring, an open circular tangible that can be placed on the table with stamps inside it (Figure 2b). When a stamp is placed in the info ring the system displays information about what resources the land-use requires and produces as well as geographic constraints on its usage. Finally, the impact stamp provides a way for children to assess the state of their world in terms of what proportion of the population has shelter, food and energy, as well as how polluted the world is (see Figure 2c). In keeping with the principles of Emergent Design, no judgment of

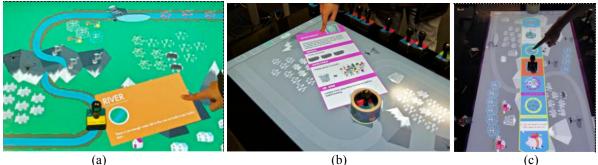
the world state as good or bad is provided; however an image of a pig asks "Is this a world you want to live in?" with the goal of eliciting a discussion of values. Use of the info ring or impact tool freezes the interaction in the system to give children time for reflection (Antle & Wise, 2013). The system was implemented on a Microsoft PixelSense digital tabletop. Usability testing to ensure basic standards were met was conducted prior to running the study. A short video of functionality is available at www.youtube.com/watch?v=o7CsEICA8nQ.

Table 1: Types of Youtopia land-use stamps

Area of Human Need	Natural Resource Stamps	Human Development Stamps
Food (green labels)	Garden, Farm <	——— Irrigation
Shelter (pink labels)	Harvest Lumber —	→ Houses, Town Houses, Apartments
Energy (yellow labels)*	Coal Mine	\longrightarrow Coal Plant
*	*	Hydro Plant

Environment (orange labels)^{**} Forest, River & Mountain Reserves

Notes: Arrows indicate which land-uses create resources required for other land-uses. *Energy land-uses *increase* the pollution in the world to different extents. **Environment land-uses *reduce* the pollution in the world to different extents



<u>Figure 2.</u> Youtopia (a) error tabs (b) info ring (c) impact tool

Research questions

As described above, in this study we sought to investigate whether assigning children roles and distributing associated controls across the TUI learning environment affected the quantity and quality of children's collaborative processes, hypothesizing that it would promote more collaborative behaviors than unscripted use of the system. In future work we will also examine effects on the outcomes of the collaborative activity. *Research Question: Does assigning children interdependent roles/ tools in Youtopia lead to increases in (a) working together? (b) talking in-depth about the sustainability domain? (c) resolving conflicts jointly rather than unilaterally?*

Methods

Research design

The study employed a post-test only experimental design. The independent variable was whether or not pairs using Youtopia were assigned particular roles with associated controls to use while they engaged in the activity. Because collaborative activity was our focus (and thus we expect learning partners to influence each other rather than be independent) pairs of children were taken as the unit of analysis. Dependent variables included measures of children's collaborative processes coded from video data and reported by children in a post-activity survey.

Participants and learning environment

Forty 5th grade children (ages 10-11, 18 boys / 22 girls) from two classrooms participated in the study in pairs (N=20). Pairs were assigned by the teachers to match children based on three criteria: one, children work well together; two, children of high ability are distributed across pairs; and three, pairs do not have one individual who is verbally dominant over the other. In addition, teachers were asked to make mixed-gender pairings to avoid differences in boy-boy and girl-girl pairs; however the class gender ratio necessitated was one girl-girl pair in each class. Pairs were randomly assigned (by the researchers) to the roles or no-roles condition, with the restriction of equal representation in each condition across the two classes. Children were mostly regular users of technology, though there were some exceptions. Due to the culture of the classrooms (and overall school) all

children had extensive prior experience collaborating. In addition all children had participated in a class unit on sustainability issues four months earlier, thus prior knowledge on the topic was generally high. The use of Youtopia was introduced as a review of the sustainability unit in which children would have the opportunity to engage in the land-use planning activity and then share and explain their final world with the class at the end.

Data collection

<u>Video</u>

Two installations of Youtopia (tabletop system, tangible objects, and associated software) were set up in separate rooms apart from the regular classroom to create a distraction-free environment. Each room was equipped with a high-definition digital video camera capturing a landscape view of the children users (and an oblique view of the tabletop surface). Video of twenty sessions of approximately a half-hour each was collected.

<u>Survey</u>

At the end of their time using Youtopia, children completed a short survey that asked them for: demographic information (age and gender); the frequency with which they used certain technologies at home; and their self-reports of (a) the process of working with their partner; (b) what they learned from the Youtopia activity; and (c) the importance / difficulty of making land-use decisions to create a world they want to live in. Full text of questions is included in the results section. For each, children indicated on whether a statement was true/important/difficult on a five point scale ranging from "not at all" to "very."

Procedure

Three research team members administered each session of Youtopia; classroom teachers were not present. Pairs were told they would have up to 25 minutes to engage in the activity. The facilitator began by introducing the children to Youtopia and giving them a basic tutorial of system functionality. Children were then invited to use the Youtopia system to create a "world they would want to live in." Specifically they were told to work together to make housing, food, energy and nature reserves and that they could change and rebuild their world until they were happy with it. No instructions were given as to what the created world should look like. Children were also made aware that after all pairs had completed their Youtopia sessions, they would be asked to share a printed-out version of their final world map and impact display with the rest of their class.

In the roles condition, one child was assigned to be the "manager of natural resources" and given all the "tree" stamps associated with this role (lumber, garden, farm, coal mine, nature reserve, river reserve, mountain reserve); the other child was assigned to be the "manager of human development" and given the "wrench" stamps associated with this role (irrigation, house, townhouse, apartment, coal plant, hydro dam). Roles were assigned randomly to children by the researchers, balancing across gender in the overall sample. Tools not associated with a particular role (impact tool, information ring, eraser tool) were placed at the end of table between the children. In the no-roles condition the pair was simply given access to all of the stamps / tools placed at the end of the table equidistant between them and grouped by color related to particular human needs (see Figure 1b and Table 1). Youtopia activity sessions were spread across the course of a week.

Data coding

Video data was coded to index two aspects of children's collaborative processes: first, the degree and type of their in-depth talk about the sustainability domain; and second, the degree of conflict they had around the sustainability domain and how it was resolved. We had initially also planned to code a more general collaboration measure of "working together" (time in which both children worked on a common element of the task); however, since all pairs in the study were seen to work together all the time, this measure was discarded and working together was indexed simply by the total time the children engaged with Youtopia.

In-Depth Events were identified as periods of Youtopia use in which one or both children explained their thinking / reasoning related to decisions about what resources and developments to use in the activity. For example "Let's build houses, not apartments-they use less lumber so we can make more nature reserves" would be coded as In-Depth, but "I think we should have houses not trees" would not. Occasions in which only one child explained their thinking or reasoning were coded as Solo In-Depth Events, while episodes in which both children explained their thinking were coded as Together In-Depth Events.

Conflict Events were identified as periods of Youtopia use in which children expressed verbal and/or physical disagreement with the other's actions or utterances related to the sustainability domain. For example if one child started to stamp a Garden and the other said "No, let's make a Farm," or one child wordlessly grabbed another's stamp it would be coded as conflict. However, if one child presented options and the other decided,

(e.g. "We could make a Garden or a Farm..." "Farm!") it was not considered conflict. Each conflict event was coded as being *Resolved Unilaterally* (one child takes action without other's consent), *Resolved Jointly* (agreement is reached before action is taken), or *Not Resolved* (the conflict was abandoned).

Three researchers were involved in coding the video data, marking all In-Depth and Conflict Events of the types described above with both a start and end time. These were used to calculate variables for both the frequency (number of occurrences) and average duration of each kind of event. Because the presence or absence of assigned roles was apparent in the videos, coders were not blind to condition. Before proceeding with the actual coding, the three researchers first used a training video to practice and refine the indicators and examples for each category. For inter-rater reliability Cohen's kappa was calculated based on the overlap of time segments coded as In-Depth or Conflict, permitting a 5 second tolerance at the start and end of events. Thirty percent (six) of the videos were double coded, three at the start of the analysis ($\kappa_{In-Depth} = .63$; $\kappa_{Conflict} = .92$). All differences in coding were reconciled.

Results

Youtopia gameplay sessions lasted between 14 and 30 min, with an average length of 23 min (SD=4.4). Examining the data set for outliers, there was one pair (roles condition) with no in-depth or conflict events of any kind throughout their entire session. Review of the video for this pair revealed that they were notably quiet compared to all other pairs and appeared to be relatively disengaged from the task throughout the session. The data from this pair was thus removed from the analysis. For the remaining 19 pairs, the data below is presented first descriptively across the entire sample and then compared across conditions. Due to the small sample size and a clearly identified hypothesized direction of effects, one-tailed tests were used.

Working together

All pairs reported high levels of working together (this was also indicated by initial viewing of the videos that led to the elimination of the working together coding); no differences were seen between the two conditions (see Table 2). The amount of time spent working together (indexed by duration of Youtopia use) was 3 min longer on average for pairs in the roles condition; however the difference failed to reach significance (Table 2).

Table 2. Mean and standard deviation of working together variables by condition

	No-Roles (N=10)	Roles (N=9)	t	$\mathbf{p}^{\dagger\dagger}$
"I worked a lot with my partner while I was doing the activity" [†]	4.35 (0.41)	4.28 (0.36)	-0.40	(.336)
"I worked mostly on my own while I was doing the activity" †	1.48 (0.45)	1.56 (0.52)	0.36	(.361)
Duration of Youtopia use (min)	21.85 (4.55)	24.99 (3.43)	1.69	.055

[†]The survey scale ran 1 to 5, with a higher number indicating a greater level of agreement with the statement

^{††} p values given are for one-tailed tests, parentheses indicate if the difference was not in the predicted direction

Talking in-depth about sustainability

Overall, pairs reported moderate levels of talking with their partner about the kind of world they wanted to live in and the degree to which they knew the kind of world that their partner wanted to live in after engaging with Youtopia (see Table 3). Counter to expectations, pairs in the no-roles condition reported somewhat higher levels of knowing the kind of world that their partner wanted to live in by the end of the activity; however even if this difference had been in the in the hypothesized direction, the effect would not have reached significance.

The total number of in-depth events per pair ranged between 2 and 19, with an average of 10 per session, accounting for ~5% of children's total play time. Looking at patterns in individual versus collaborative in-depth talk across *all* pairs, on average there was a greater frequency of solo in-depth events (M=7.26, SD=3.90) than together in-depth events (M=2.95, SD=2.32) [$t_{18} = 6.31$, p < .001]. However, when they occurred, the together in-depth events had longer average durations (M=10.37 sec, SD=4.37) than the solo in-depth events (M=4.33 sec, SD=1.09) [$t_{16} = 5.39$, p < .001]. (Note that these are comparisons between event types across all pairs and thus different from the comparisons across condition shown in Table 3). Comparing role and no-role conditions, the number, but not length of solo in-depth events was greater for pairs in the roles condition. However, no differences were seen in the number or length of together in-depth events (see Table 3).

Table 3. Mean and standard deviation of talkin	g about sustainabilit	y variables b	y condition

	No-Roles (N=10)	Roles (N=9)	Т	$p^{\dagger\dagger}$
"My partner and I talked a lot about the kind of world we want to live in" [†]	3.58 (0.87)	3.39 (0.65)	-0.52	(.303)
"After playing the game together, I know what kind of world my partner wants to live in" [†]	4.20 (0.48)	3.81 (0.68)	-1.47	(.080)
Solo In-Depth Events - Frequency (number)	5.80 (2.86)	8.89 (4.40)	1.83	.042
Solo In-Depth Events - Average Length (sec)	4.35 (1.05)	4.37 (1.12)	0.06	.957
Together In-Depth Events - Frequency (number)	2.60 (2.12)	3.33 (2.60)	0.68	.254
Together In-Depth Events - Average Length (sec)	10.89 (5.14) ***	9.78 (3.58) ***	0.51	.619

[†]The survey scale ran 1 to 5, with a higher number indicating a greater level of agreement with the statement

^{††} p values given are for one-tailed tests, parentheses indicate if the difference was not in the predicted direction

^{†††} N in this cell was reduced by one, after removing a pair that did not have any In-Depth Together Events

Engaging in and resolving conflict

The data distribution for conflict was heavily skewed and kurtotic due to a substantial number of pairs without any conflict events; thus assumptions of normality were considered to be violated and non-parametric tests were used. The predicted increased frequency in unilaterally resolved conflict events for the no-roles condition was observed (see Table 4). However unexpectedly results showed the no-roles condition also had a greater frequency of jointly resolved conflict events; had our hypothesis for this variable been in the opposite direction, the difference would have been significant. There were few unresolved conflict events in either condition. As there was only one instance of unilaterally resolved conflict events. However jointly resolved conflict in the roles condition lasted significantly longer than jointly resolved conflict in the no-roles condition.

Table 4. Median frequency and duration of conflict event variables by condition

	No-Roles ((N=10)	Roles (N=9)		Mann-Whitney p	
	Median	Max	Median	Max	(one-tailed)	
Unilaterally Resolved Conflict Events						
Frequency (number)	0.5	4	0	1	.030	
Av Length (sec)	6.67^{\dagger}	12.5	$4.4^{\dagger\dagger}$	4.4	-	
Jointly Resolved Conflict Events						
Frequency (number)	1	8	0	3	(.029)	
Av length (sec)	9.32 ^{†††}	22.7	32.73 ^{††††}	50.5	.031	
Unresolved Conflict Events						
Frequency (number)	0	1	0	2	.350	
Average Length (sec)	12.61*****	23.06	36.39 ^{††}	36.39	-	

Notes: Removing pairs that did not have any conflict events resolved in the indicated way, left the following cell sizes: $^{1}N=5$, $^{1+}N=1$, $^{1++}N=8$, $^{1+++}N=4$, $^{1++++}N=2$, Mann-Whitney test was not run if combined N across cells <10

Discussion

Summary of results

Pairs of children reported generally high levels of working together and moderate levels of talking with their partner about the kind of world they want to live in, with no differences between conditions. Pairs in the roles condition spent a few minutes longer engaging with Youtopia and pairs in the non-roles condition described slightly higher levels of knowing the kind of world that their partner wanted to live in; however both differences failed to reach significance. Overall, events in which children talked in-depth about sustainability issues represented a small portion (5%) of their total session time, with solo in-depth talk occurring twice as frequently as together talk; however the together in-depth talk lasted twice as long. On average pairs assigned roles had one and a half times as many solo in-depth events than those who did not have roles. No differences were seen for the length of these events or the length or frequency of together in-depth events. Pairs without roles assigned

had more unilaterally and jointly resolved conflict events than pairs who were assigned roles; however when pairs with roles engaged in jointly resolved conflict it lasted approximately three times as long.

Overall collaborative patterns

Before comparing the roles and no-roles conditions, it is useful to examine some of the overall collaborative patterns observed. First, pairs in both conditions worked together for the entire time of the activity. This is a positive finding amidst concerns about parallel independent play and competitive behaviors (Marshall et al., 2009). This may be a result of the game design, the classroom culture of collaboration set up by the teachers (Hakkarainen et al., 2002), the pairing of kids who worked well together by teachers or other factors. However, the proportion of the time working together that was identified as "in-depth" talk about the sustainability domain was only 5%. This may be in part because the bar for identification of in-depth events was set quite high, requiring children to talk about tradeoffs in the game and reasons for tradeoffs that involve environmental values (thus when this talk did occur it was very rich). In future work it may be necessary to relax these requirements to include a larger swath of relevant talk; however this also highlights an important point about CSCL analyses-that the "golden moments" in collaborative learning we aspire to (and see highlighted in the research) are often farther and fewer between than we would like to think. Interestingly, there is some indication in this study that the children themselves were aware of this difference, reporting high levels of working with their partner but only moderate levels of talking with their partner about the kind of world they want to live in. Overall there was a lack of conflict in this study with a substantial number of pairs having no conflict events at all. This may again be due to the classroom culture and/or pairing strategy used. Still, it is of potential concern since the negotiation and integration of differing perspectives is at the conceptual core of collaborative learning (e.g. Andriessen et al., 2003). Finally, solo in-depth events outnumbers together in-depth events two to one, suggesting an overall prevalence of explanation over negotiation. This is discussed further below.

The effects of assigning interdependent roles and tools

One effect of the interdependent roles and tool assignment was that pairs in the roles condition had more solo (but not together) in-depth events than pairs in the no-roles condition. This is an interesting and somewhat surprising finding since it was expected that the interdependent roles/tools would support children in discussing the sustainability tradeoffs and decisions they needed to make together. Instead, it seems that the role/tool assignment led the children to explain what they were doing to each other more often, but not necessarily negotiate it (note that an in-depth statement about a choice to be made in the environment that received a simply affirmative reply like "okay, good idea" would have been coded as a solo in-depth event because even though both children spoke, the second comment was not in-depth). In some sense then this is a positive finding since simply getting children to externalize their thinking and rationale may have benefits for reflective processes. collaboration, and learning (Price et al., 2003). However, we are curious as to why in-depth statements about sustainability and game choices did not consistently lead to substantive replies. One possibility is that children were too willing to agree with their partner (or unwilling to question them) in an effort to maintain harmony. Challenges in getting learners to disagree have been reported in CSCL environments previously (De Wever et al. 2008). However, that issue does not speak to why children didn't build on their partner's ideas. Again this may relate to the particular classroom culture of collaboration or perhaps that the game dynamics promoted taking (and seeing the effects of) decisions one step at a time, delaying the moment at which it is appropriate to build-upon a partner's idea until after the first decision has been enacted. We also note that this reflects a larger trend of solo over together in-depth events across the sample more broadly. Further investigation of the issue through examination of sequences of turn-taking is an interesting area for future research.

A second effect of the interdependent roles and tool assignment was that children without roles assigned had both more unilaterally resolved conflict events and jointly resolved conflict events. The greater number of unilaterally resolved conflicts was expected; in the absence of interdependent roles with associated tools, either child could make and enact a decision on the game board without gaining their partner's agreement. However the greater number of jointly resolved conflicts was not predicted; in fact it was expected that the positive interdependence of the roles condition would lead to more jointly resolved conflict. The cause of this effect remains unknown; it may be that in the absence of being assigned a particular perspective, each child was able to consider both sides of an issue of conflict and thus more easily detach themselves from their original view to come to a joint agreement. In the no roles condition both children could also undo or redo a game action at any time, making the cost of agreement relatively low. This hypothesis is supported by the additional evidence that when jointly resolved conflicts did occur in the roles condition, they lasted significantly longer. This may be because children given a role with responsibilities and tool ownership were more attached to their positions, thus it took longer for them to reach a resolution satisfactory to both parties. Whether this extended

period of dialogue involved a deeper negotiation around values that benefited their learning about sustainability is an important area for investigation. Follow-up work is currently underway to investigate this through both a qualitative examination of the dialogue episodes and a quantitative assessment of changes in understanding.

Limitations

There were several limitations to this study relating to the relatively small sample size, children with atypically high prior knowledge and experience collaborating, and the high bar of coding criteria for in-depth events. Future work should expand the number and diversity of children studied with an updated coding protocol.

Conclusion

This paper presented an in-vivo experimental study of the effects of assigning children roles with associated tools in a sustainable land-use planning game. Contrary to some previous findings, all pairs in both conditions were found to work together (rather than in parallel / competitively) the entire time. Results showed that pairs given specific roles/tools gave more in-depth explanations to their partners about what they wanted to do in the game than pairs not assigned roles and tools, but did not negotiate with each other in-depth more frequently. This reflects a trend of explanation over negotiation in the sample more broadly. Pairs assigned roles also had fewer but longer instances of jointly resolved conflict. Thus our general finding is a somewhat limited, but consistent, positive effect of the assigned roles/tools manipulation on collaborative processes.

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Investigating Collaborative Reflection with Peers in an Online Learning Environment

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Abstract: In this study, a group of 22 vocational school teachers wrote weekly reflections in an online learning environment after attending a lesson. They also read the reflections written by others and gave comments. The purpose of this study was to find out how they reflected collaboratively in the online learning environment and what they learned from the collaborative reflection process. Results show that they could reflect on the lesson content and link it to their teaching practice. Also, their peers could get additional perspectives, negotiate meaning, and learn how to reflect better from the reflection shared. Furthermore, they could also gain additional knowledge and emotional support from their peers' comments. This paper describes the design of the study, and the themes that emerged from the reflection, comments, and responses. Benefits of writing collaborative reflection with peers in an online learning environment and issues involved in the study are discussed.

Keywords: collaborative reflection; Edmodo; individual reflection; online reflection; teacher education; technology

Introduction

Being able to reflect on what they have learned from a training session and further apply it to teaching practice is an essential competency for school teachers in the current information age, as it enables them to examine the relevance of the training content and improve their teaching practice to meet the constant change of students' learning needs (Killeavy & Moloney, 2010). Reflection can be written in different ways such as individually or collaboratively. Individual reflection may enhance the development of insight, heighten cognitive awareness, promote critical thinking, and engender personal transformation. However, recent proponents of reflection have challenged the assumption that reflection occurs solely in isolation (Morris & Stew, 2007), and suggest that reflection should be a collaborative critical thinking process, in which participants can 'attain intersubjective understanding and build knowledge together' (Yukawa, 2006, p.207).

Collaborative reflection can also be carried out in different settings such as online or face-to-face, and with different people like the teacher or peers. Some existing research studies have examined how learners collaboratively reflect with the teacher in face-to-face settings (e.g. Morris & Stew, 2007) or in online settings (e.g. Yakawa, 2006). Other studied have investigated how learners reflect or discuss with their peers in online spaces (e.g. Killervy & Monoley, 2010; Yang, 2009). However, these studies usually focus on the affordances of the online tools (such as a weblog or a discussion forum) for collaborative sharing and discussion. Very little literature reports on how learners reflect collaboratively with their peers and what they learn from each other in an online environment.

The purpose of this study was to investigate how a group of vocational school teachers reflected in an online learning environment after attending training lessons, and how their peers commented on the reflection and what the peers learned from the reflection. Furthermore, this study also examined how they responded to the comments received from the peers and what they gained from the comments. This paper describes the research design of the study, and the themes emerged from the reflection, comments, and responses.

Collaborative reflection

Compared to individual reflection, collaborative reflection is a step further. In addition to making the connection between the new content with their existing knowledge, learners also share their individual understanding and get feedback from others, as shown in Figure 1. Much literature also argues that individual reflection may obstruct professional development and it should involve external dialogue with others such as the teacher or peers (Clarke, 2003; Hawkes & Romiszowski, 2001).

Many existing research studies report on collaborative reflection between learners and the teacher (Wang & Woo, 2010; Yukawa, 2006). The advantage of collaboration with the teacher is that learners can get expertise and support from the teacher, but learners may not disagree with the teacher's opinions or examine his/her comments critically, owing to the perceived expertise of the teacher or the imbalanced power

relationship (Bye, Smith, & Rallis, 2009; Leijen et al, 2009). Also, the quality of the teacher may heavily affect the level of collaborative reflection (Morris & Stew, 2007).

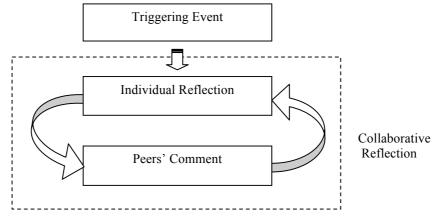


Figure 1. Illustration of collaborative reflection

Comparatively, collaborative reflection between learners and peers is more of a reciprocal process. By reading through published reflection, peers would have the possibility to get valuable alternative perspectives from their shared reflection (Leijen et al, 2009; van Gyn, 1996). Also, they may gain additional insights from the peers' comments. Through the interaction and communication, learners and their peers can achieve mutual understanding and build knowledge together (Yukawa, 2006).

No matter collaborative reflection occurs with the teacher or peers, an often reported benefit is the release of learners' stress and the expression of their emotions. Research shows learners often reflect on the aspects which they did wrong, but ignore positive aspects (Leijen, et al, 2009). Through collaborative sharing and reflection, they can find out that they are not alone in their feelings (Glazer, Abbott, & Harris, 2004). They may also get emotional support from the feedback received (Nicholson & Bond, 2003; Yakawa, 2006).

Many existing studies examine collaborative reflection in face-to-face settings, such as those done by Glazer, Abbott and Harris (2004), and Morris and Stew (2007). Collaborative reflection in face-to-face settings has many benefits such as enabling participants to clarify ideas or get feedback immediately. However, participants are often hard to find time to meet together (Glazer, Abbott, & Harris, 2004), and reflection minutes are not automatically recorded (Wang, 2010). On the other hand, the fast growth of technology has made writing reflection in an online learning environment not only feasible, but also more effective than in a face-to-face setting (Wang & Woo, 2010).

Learning is a highly social process according to the social constructivist learning theory. As learners' individual understanding on the same topic may be different, having an opportunity to share and negotiate their understanding with peers would enable them to get various perspectives from others and hence understand the topic better. In this study, collaborative reflection is defined as a reciprocal critical thinking process of learners, who share their understanding in an online learning environment after attending a lesson, give comments to the reflection written by peers, and respond to the comments received, so that they can reach mutual understanding and construct meaningful knowledge together.

Methods

Participants and course description

A total number of 22 (14 females, 8 males) vocational school teachers from China participated in this study, when they were studying as full-time Master students at National Institute of Education in Singapore for a year, majored in the subject of educational management. Their age ranged from 25 to 49. They had different backgrounds. Half of them were vice principals or deans, and the others were subject teachers. About one-third had more than 15 years of teaching experience, and the rest had an average of 7 years. Their teaching subjects included English language, computers, sports, nurse education and others. Their technology competency varied according to their subjects and ages.

The course entitled Educational Technology and Issues in Management ran three hours a week and lasted for six weeks. The lessons involved both theories and hands-on activities. The theories included affordances of web 2.0 tools, design and evaluation of web-based courses, and technology supported

professional development. The hands-on activities provided them with opportunities to explore simple ICT tools such as Blackboard and Lesson Builder.

One of the course assignments was to write weekly collaborative reflection in the first five weeks. Each reflection was supposed to include what they had learned in the lesson and how to apply it into practice. The participants were required to share their individual reflection in Edmodo (http://www.Edmodo.com) with their peers. Also, they must view and give comments to at least two reflection posts written by others. Each reflection was 10 marks, of which their individual reflection and comments had five marks respectively.

To ensure the collaborative reflection process to occur smoothly, some ground rules were established in the first session. By each weekend, they had to complete their individual reflection and submit to Edmodo. Between the weekend and the next session, they had to give at least two comments to the reflection posts written by others.

Research questions, data collection and analysis

The assumption of writing collaborative reflection in this course was to get the participants gaining knowledge not only from the instructor, but also from their peers. The purpose of this study was to investigate how they collaboratively reflected with each other and if they learned something useful from their peers and what they learned. The main research questions were:

- How did they reflect collaboratively?
- What did they learn from the collective reflection process?

Following the traditional grounded theory (Strauss & Corbin, 1990), this study adopted the constant comparison approach. All reflection posts, comments and responses posted onto Edmodo were copied to a word document. The reflection of the first participant was read carefully in paragraphs, and the way of writing reflection was color coded for easy recognition later. After analyzing all reflection posts of the first participant, the researcher compiled the codes to further consolidate common themes.

The coding process continued in a similar way with the rest of the participants. If a new theme emerged, it would be added to the theme list. After reading through all reflection posts, common themes emerged from the reflection were generated. The themes were further compared and combined. A list of two to four themes was finally summarized. The same approach was applied to analyze the comments and responses. The following section reports on the common themes identified in the reflection, comments, and responses.

Findings

Reflection

Altogether 110 individual reflection posts were found in Edmodo and 184 codes were labeled. As shown in Table 1, three main themes emerged from the reflection, which were: i) elaborating on the content; ii) applying the content into practice; and iii) changing beliefs.

Table 1: Themes emerged from the reflection

Theme	How/What	Ν	%
Elaborating on	- Reiterating/summarizing what	49	26.6
content	they learned	31	16.8
	- adding new information	9	5.0
	- linking to existing content		
		89	48.4
Applying the	- explaining existing phenomena	58	31.5
content into practice	- solving real problems	26	14.1
F		84	45.6
Changing beliefs	- rethinking about their beliefs	9	5.0
	- transforming their beliefs	2	1.0
		11	6.0
	Total	184	100

Elaborating on the content

Reflecting on the lesson content was a basic requirement for the individual reflection. The participants elaborated on the content in slightly different ways. The most often used way was that they simply repeated what they had learned from the lesson, summarized some points from the instructor's presentation, or added certain personal understanding but without in-depth explanations (N = 49, 26.6%).

Another way was that they elaborated on the content further by adding new information (N = 31, 16.8%). It was evident that they went to the Internet to search for additional information for better understanding the contents that were new to them. In their reflection, they shared the additional information. For instance, a participant wrote in his reflection:

Today what impressed me most was the constructivist learning theory. Previously I knew little about it. After the class, I went to the Internet to look for the definitions of constructivism. Some of the definitions are... (Lin Botao)

An additional way of writing reflection was they elaborated on the content by connecting it to previous lessons, reflection, or content learned from other instructors (N=9, 5.0%). It seemed that they attempted to integrate the newly learned content into their existing knowledge structure.

Applying the content into practice

Two ways of applying the newly learned content into practice was found. One way was that they attempted to explain certain existing phenomena by using the content (N=58, 31.5%). For instance, one strategy to promote constructivist learning is to make the learning task meaningful to learners. A participant linked this strategy to her experience of learning an English word. She said:

I still remember how I learned the word of 'smother' many years ago. The teacher told that in order to remember its meaning, we could imagine that a mother was careless and her child was finally 'smothered'. I think this is the power of making leaning tasks meaningful (Zhang zhen)

The other way was that they applied the lesson content into real world problem solving (N=26, 14.1%). After studying how to design web-based courses, a participant came up with an idea of designing a web-based course, in which a learning activity was to establish a supermarket in Singapore. He wrote:

Through the activity of establishing a supermarket in Singapore, students can learn practical knowledge about laws, geographical information, economics, and goods information. By doing this activity, students can learn and construct knowledge by themselves. Designing this course will be more useful than teaching them directly (Shao Feng)

Changing beliefs

Another theme emerged from the reflection was the newly learned content stimulated them to rethink about their underlying beliefs and as a result their assumptions started to transform (N=11, 6.0%). For instance, before the lesson about using the weblog for teaching and learning, some of them thought that the weblog was a tool for writing personal diaries or sharing information with friends only. They seldom thought that it could be used as a teaching or learning tool. After seeing some examples, they realized the potential of the weblog for learning and thereafter their opinions started to change.

Another example was that a participant started to believe that using technology was not that difficult after exploring some simple technological tools in this course. In her reflection, she wrote:

I seldom thought of using technologies to enhance my teaching before because I felt it was quite troublesome and there might be a lot of technical problems. In the past few sessions, we explored a few simple but quite useful tools such as weblog and Edmodo. I feel using technology is not that difficult and effectively using it would enable students to learner better. I will try to use technology more frequently in the future (Zhu yuhong)

Comments

Altogether 326 comments were posted to Edmodo and 336 codes were identified. As shown in Table 2, four major themes became apparent in their comments, which were: i) commenting on the content; ii) expressing encouragement; iii) commenting on the way of writing reflection; and iv) bantering with peers.

Table 2:	Themes	emerged	from	the	comments

Theme		How/What	N	%
Commenting on the	-	elaborating on the reflection	134	39.9
content	-	articulating agreement	92	27.4
	-	negotiating meaning	24	7.1
	-	articulating disagreement	14	4.1
	-	learning new content directly or indirectly	13	3.9
		2	277	82.4
Expressing encouragement	-	encouraging or being encouraged	27	8.0
Commenting on the way of writing reflection	-	respecting the positive attitude towards reflection/learning	17	5.0
Bantering with peers	-	sharing jokes	9	2.7
C 1	-	using nicknames	6	1.9
		2	15	4.6
		Total	336	100

Commenting on the content

Peers used to further elaborate on the reflection content in their comments (N=134, 39.9%). Slightly different ways of making comments were found. One way was that they picked up certain keywords or points from the reflection and elaborated further by adding new information or explanations. Another way was they attempted to offer solutions to some problems mentioned in the reflection or to explain why the problems existed.

Peers also expressed opinions in their comments. They might add personal experiences or additional arguments to support the opinions embedded in the reflection (N=92, 27.4%), or disagreed with certain ideas in the reflection by providing with different examples or perspectives (N=14, 4.1%). The following comment shows how a participant disagreed:

I think you are too optimistic about constructivist learning with vocational school students. I feel it is a bit hard for the students to construct knowledge as their learning abilities are rather low. They even don't know what to learn, needleless to say how to construct (Liu Ruiyan)

In certain cases where the reflection content was unclear, peers tended to negotiate meaning by asking questions, giving a different interpretation, or asking for more information (N=24, 7.1%). For example, a participant mentioned in her reflection that constructivist learning might not be feasible for low-ability students. She thought teachers had to consider students' abilities when they were designing lessons and to provide different learning activities to different ability students. After this reflection, a peer in his comment wrote:

I think what you mean is 'yin-cai-shi-jiao' (a Chinese idiom, which means teaching according to the student's ability). My view is different and may be incorrect. It is exactly because various students can construct, they have rich knowledge. We should allow different-ability students to construct knowledge, and the initial knowledge constructed can be wrong. They can learn from errors. What do you think? Waiting for your critique (Wang Shu)

In some comments, peers also stated what they learned from the reflection (N=13, 3.9%). They indicated that they either learned directly from the published reflection, or benefited from the reflection in an indirect way as certain ideas in the reflection triggered them to search for more information or study further.

Expressing encouragement

In addition to giving comments to the content, peers also expressed encouragement in their comments (N=27, 8.0%). Generally, peers gave encouragement in two situations. One was that peers gave encouragement when they realized the reflection writer had certain problems or difficulties, and the other way was that they gave positive comments or encouragement when the reflection writer presented good ideas, comprehensive summaries, or constructive suggestions. The following two quotations show how a peer encouraged the reflection writer and how another peer was encouraged respectively:

From your worries I deeply feel how much you love your profession, your students, and our home country. The conditions in our country are lower but improving very fast. We should believe our school facilities will become better in the future... (Xiong Ying)

Commenting on the way of writing reflection

Sometimes they did not comment on the reflection content, but on the way of writing reflection (N=17, 5.0%). What impressed them most was the responsible way of writing reflection, or the positive attitude towards reflection writing or learning in general. The following quotation shows how a peer commented on the way of writing reflection:

This is a very detailed and in-depth reflection. I did not link the content to practical problems and my reflection stayed at a surface level. After reading your reflection, I understand what is 'xue-er-bu-si-ze-ming'(learning without thinking is useless) (Xiang Guohong)

Bantering with peers

One way of bantering was they joked with each other (N=9, 2.7%). For instance, after reading a reflection post about how easy to communicate with others at a distance by using instant messaging tools or email, a peer wrote in her comment that:

Cheng cheng, if I want to talk to Qing-shi-huang (an ancient Chinese emperor lived more than 2000 years ago), which tool should I use, instant messaging, mobile phone, or email? I am waiting for your reply (Xiong Ying)

Another way was that they occasionally addressed others by nicknames (N=6, 1.9%). A participant who has a word of 'Xiang' (which is the elephant in Chinese) in his name, his peers often called him 'a big elephant'. It seems that he was acceptable with this form of address and no indication showed that he was unhappy with it. Another participant was often labeled 'xian zhi' (which means a prophet) in her peers' posts.

Responses

This section describes how the participants responded to the comments received and what they gained from the comments. Although the assignment did not require the participants to respond to the comments received, many of them did spontaneously. Altogether 30 responses were found and each response was associated with a code. As shown in Table 3, two main themes arose from the responses, which were: i) responding to the comment content; and ii) responding to the emotional support received.

Theme	How/What		%
Responding to the comment content	- providing further explanations	12	40.0
	- acknowledging the contribution of comments: extending the breadth or depth of reflection	8	26.7
	1	20	66.7
Responding to emotional support	- felt encouraged or not alone	10	33.3
	Total	30	100

Table 3: Themes emerged from responses

Responding to the comment content

Many responses were to answer the questions asked in the comments or to provide additional information to further explain their opinions (N=12, 40.0%). For instance in a reflection post, Mrs. Wu indicated that she created some animations when she was teaching a course and found the students learned better by using the animations. However, she pointed out that creating animations was complicated and time consuming. In the following comments, she was suggested asking students to create. If so, students would learn the topic better and she could also collect good artifacts for future use. In the response, she argued that she did ask students to create but failed, and further explained why it did not work.

Some responses were to acknowledge the contribution of comments (N=8, 26.7%). It seemed that the comments made two major contributions: One was that the comments extended the breadth of their original reflection. They thought the comments made the reflection content more complete, as they provided additional perspectives or explanations. The other contribution was that the comments extended the depth of their reflection, as these comments explained why certain phenomena happened or how to address the problems/issues involved in the reflection. Such comments enabled them to understand the problems better or promoted their understanding to a higher level.

Responding to emotional support

The participants sometimes got emotional support from the comments received and felt encouraged (N=10, 33.3%). For instance in a reflection post, Ms. Tan became quite depressed after comparing the use of technology in Singapore schools and in her own school in China. She described some of the problems she encountered in her prior teaching practice. In a comment, she was comforted that the school facilities had been better than before, and the school condition in China would be catching up. After receiving the comment, she replied that:

Thanks for your comfort and encouragement. I also hope the school condition would become better, the gap will be narrowed down, and the use of technology in schools will be improved faster in the future (Tan Jingyun)

Discussion

Collaborative reflection has additional benefits than individual reflection. In addition to learning content directly from the lesson or the instructor, the participants in this study also shared their understanding with peers. Through the sharing, peers learned additional information, different perspectives, or the way of writing from the reflection. Also, the comments given by peers extended the breadth or depth of their original understanding. Obviously without sharing and interacting with others, these benefits would be hard to gain. This finding confirms the outcomes of other studies done by Yukawa (2006), Morris and Stew (2007), and Yang (2009), who claim that collaborative reflection is a reciprocal critical thinking process, in which learners can gain knowledge from each other, and develop professional knowledge together.

Collaborative reflection can also lead to higher level thinking and transformational changes. In addition to reflecting and commenting on the lesson content, the participants in this study also reflected on the way of others' writing reflection, which is closely related to what Mezirow (1991) called process reflection. This study also showed that through collaborative reflection, participants demonstrated certain changes in their beliefs. Belief change is associated with premise reflection (Mezirow, 1991). In addition, the result further extends the finding of Killeavy and Moloney (2010), who found that learners merely involved content reflection, not process or premise reflection in their weblog-based reflection.

Collaborative reflection involves both cognitive and affective processes. In this study, the participants did not only reflect on content, but also gave encouragement or emotional support to others. The participants appreciated the support and felt encouraged. This study supports the notion that collaborative reflection is an integrated process, in which affective interactions help to build and maintain positive relationships among participants and hence promote their cognitive development (Nicholson & Bond, 2003; Yukawa, 2006).

Some benefits of collaborative reflection are associated with the online medium only. Online reflection provides a more equal opportunity for a group of participants to share and discuss ideas. Comparatively, the face-to-face discussion is often controlled by a few vocal participants and therefore the conclusion may be biased (Wang & Woo, 2007). Online reflection can extend their sharing beyond the classroom. The discussion in the classroom may not reach a consensus due to the time limitation. The online reflection can become another venue for them to continue their sharing and discussion (Nicholson & Bond, 2003; Slavit, 2002).

Online reflection makes the communication process more transparent. As all communication minutes are recorded down automatically, participants can easily refer back to the previous posts. This would enable them to easily make connections between what they have just learned and what obtained before (Wang, 2010;

Yukawa, 2006). Undoubtedly, without these affordances of an online tool such as Edmodo, the results of this study might be compromised.

This study has some implications for collaborative reflection to take place effectively. A few learners are preferably more experienced in terms of teaching experiences or critical thinking skills, so that they can act as positive role models to others. In this study, some participants were more experienced or responsible. Their reflection was in more depth. The others commonly indicated that they learned how to reflect from these learners. This finding suggests that involving some higher ability or more experienced learners would show a positive sample to others and hence has the possibility to promote collaborative reflection to a higher level.

Another implication is that learners are favored to have different backgrounds. In this study, the participants varied in their ages, positions, teaching subjects, or teaching experiences. Because of the difference, they could explain the same content or phenomenon from different perspectives, or give varied interpretations. This result implies that having different background learners would increase the likelihood of gaining more benefits from peers in the collaborative reflection process.

Writing collaborative reflection with peers in an online learning environment has a number of benefits. Learners can share their understanding with their peers in the online learning environment. Also, peers can learn different perspectives or positive attitude towards learning from the reflection they shared. Their peers also have enough time to think about the reflection, and provide additional perspectives or encouragement, from which they can gain emotional support or extra information to further extend their original understanding. This study confirms that collaborative reflection with peers is a reciprocal learning process for learners to support and learn from each other and construct knowledge together.

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Algebra Learning through Digital Gaming in School

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Abstract: Digital games have sparked research interest into how they can be used in school to enhance learning. This study identifies the variation in engagement and learning outcomes when two groups of students use two different digital learning resources for algebra: a game and a web-based resource. Further, the study explores how the digital learning resources create different conditions for social interaction and learning among students and their teacher in a classroom. The setting includes a class of 75 students (age 13–14) in two groups who receive identical instruction from their teacher. Field observations and pretests and posttests show that students playing the game are more engaged, yet their performance on posttests are significantly worse than the other group. Episodes of interaction between participants and technology suggest that they struggle with the symbolic world of the digital game, which constrains the mathematical meaning making that is relevant in schools.

Keywords: Digital games, algebra, mixed methods, engagement, learning outcomes, meaning making

Introduction

Play has been noted by several educational psychologists as important in order for children to construct knowledge and learn (e.g., Piaget, 1951; Vygotsky, 1978). Today, a considerable amount of children's play is dominated by digital gaming on various platforms such as laptops, tablets, and smartphones. Thus, the phenomenon of digital games has sparked research interest in how they can be used in school to enhance learning (e.g., Gee, 2003; Prensky, 2001). This mixed-method study investigates how two digital learning resources for algebra—an award-winning digital algebra game and a web-based learning resource—create different conditions for social interaction and learning among students and with their teacher in a classroom.

Currently, there is no agreed upon definition of what a digital learning game is (Granic, Lobel, & Engels, 2014; Tobias & Fletcher, 2012; Young et al., 2012). Several researchers emphasize that a central aspect in a learning game is that it should be a voluntary activity structured by rules with a defined outcome that facilitates comparisons of in-player performances (Young et al., 2012). However, as others (e.g., Arnseth 2006) have noted, such a notion contains a tension because although game playing usually is voluntary, schooling is not. Thus, because schools are less voluntary, other terms to describe digital learning games have emerged such as "serious games" and "educational games" (Tobias & Fletcher, 2012).

The current debate in game-based learning research focuses mainly on how various types of games or elements from such games can be efficient for learning in classrooms (Tobias & Fletcher, 2012; Young et al., 2012). A meta-analysis provided by Young et al. (2012) indicates that game-based learning can have a positive effect on subjects such as language learning, history, and physical education. However, in the case of mathematics, the results are mixed. According to Young et al. (2012), math games often have a positive effect on engagement but no significant effect on learning outcomes. Nonetheless, there are case studies that show positive effects in terms of learning outcomes in mathematics (e.g., Habgood & Ainsworth, 2011; Kebritchi, Hirumi, & Bai, 2010). More recently, researchers have begun focusing on game-based learning from a social and situated perspective on learning in which the effects are downplayed (e.g., Arnseth, 2006; Silseth, 2012; Young et al., 2012). The argument is that we need to know how students and teachers constitute digital games into learning resources in classrooms, and we need to study how students and teachers interact to make the game meaningful for their specific learning purposes. In this paper, our aim is to contribute to this debate by investigating the following research questions:

- Can we identify any variation in engagement and learning outcome when students use the two digital learning resources—a digital algebra game and a web-based learning resource—for algebra?
- How do the two digital learning resources create different conditions for meaning making and social interaction among students and their teacher in the classroom?

In this paper, we understand learning as socially mediated in and through interpretation and mastery of historical tools and practices (Säljö, 2001; Vygotsky, 1978). Learning is seen as related to the situation that it occurs in, which includes the institutional and historical frames, specifically in the form of formal and informal norms and regulations that exist for the activity. In this perspective, the constructive aspects of learning are

studied, that is, the students' and their teacher's activity and how interactions and utterances are expressions of the participants' meaning making.

Digital gaming in classrooms

As previously noted, meta-analyses of effect studies in game-based learning have found evidence that gamebased learning generally has a positive effect on school subjects such as language learning and history (Young et al., 2012). However, in the field of mathematics, the results are mixed (Ke, 2008; Kebritchi et al., 2010; Young et al., 2012). Ke (2008) reports on a mixed methods study examining whether digital learning games, in comparison to traditional paper-and-pencil drills, would be more effective in facilitating learning outcomes in math, and whether alternative classroom goal structures would enhance or reduce the effects of digital games. Ke used eight web-based math games in the ASTRA EAGLE game series during 20 hours over 5 weeks in a summer camp for fourth-fifth graders (age 10-13). Pretests and posttests with a control group show that the students significantly improved their attitudes toward math through gameplay, but there were no significant effects on test performance measured by national test standards. Qualitative data, such as field observations and talk-aloud protocols, revealed several problematic issues, including the pattern of "wandering mouse and random clicking." This pattern may express guessing and lack of direction. Ke points out that playing a game in itself may promote this usage pattern in order to be fun, but it may not contribute to learning. Ke argues that when designing digital learning games, one might consider integrating goals of gameplay with curriculum goals. A suggestion is to integrate these two aspects in the gameplay in such a way that fantasy depends on the practice of skills, and vice versa.

One approach to integrating goals of gameplay with curriculum goals that has gained support in digital learning games is "stealth learning" (Ke, 2008; Prensky, 2001). In this approach, engagement is emphasized, but formal learning is hidden from the student or player. Through play and engagement, the students take part in productive interactions from a learning perspective but without elements the students affiliate with didactic instruction. One study related to this approach is Habgood and Ainsworth (2011) and their concept of "intrinsic integration" in which they designed a game about fractions in a way that puts the essentials of formal learning content inside the critical parts of the gameplay. Compared to games where formal learning is "extrinsic," that is, designing the learning elements into the peripheral parts of the game, intrinsic integration is designed to merge fun with formal learning seamlessly and simultaneously. Habgood and Ainsworth's mixed methods study of children (age 7) shows positive results of "intrinsic integration" compared to two control groups, which played the same game but without "intrinsic" versions of the game. A lesson learned from Habgood and Ainsworth's study is that there is a risk of students "staying in the game," meaning they are unable to break out of the specific condition of the game and cannot apply the knowledge they construct in the game outside game settings. Although Habgood and Ainsworth show positive results, they recognize that it is difficult to bridge actions and what is learned within the game to interactions and procedures normal to a classroom setting. This problem, also noted by Ke (2008), emphasizes the bridging of symbolic interactions within the game with outside interactions such as talking about and solving standard mathematical problems with other resources such as textbooks, paper notebooks, and whiteboards.

Although Ke (2008) and Habgood and Ainsworth (2011) provide us with important information regarding to which degree a game may be considered successful in a classroom context, we still need to understand how the students' and the teacher's understanding of and interactions with a game unfold through hours of gameplay in a school context. Silseth (2012) explores how the computer game "Global Conflicts: Palestine" becomes a learning resource for working with the complexity of the Israeli-Palestinian conflict in school. The aim of his study is to understand how interactions in a gaming context constitute a student's learning trajectory. Silseth applies a dialogic approach to learning, which is an important line within CSCL research, and he observes students at an upper secondary school (age 16-17) for four weeks. By analyzing various interactional episodes, he documents how a student's learning trajectory developed and changed during the project. Silseth's findings suggest that the constitution of a computer game as a learning resource is a collaborative project between students and their teacher. The teacher plays an important role in prompting and guiding the students in various ways to make them collaboratively reflect on their viewpoints and choices made in the game, as well as facilitating the students' adoption of a multiperspective on the conflict. Although Silseth's study is not within the field of mathematics, it is important to note how he goes beyond mere effects of game-based learning to unpack the interactions between students and their teacher and illustrate how the game's function changes over time in a student's learning trajectory.

Our study examines the use of two different digital learning resources, Kikora and DragonBox. The teacher wanted to use these to vary his teaching. This gave the researchers the opportunity to compare the two in terms of engagement and learning, as well as how they create different conditions for meaning making and

social interaction among students and their teacher in the classroom. It is a natural setting and the researchers do not manipulate the classroom practices in this study. We will now briefly describe Kikora and DragonBox with an emphasis on what is most relevant for our study.

Kikora

Kikora is a web-based learning resource in which problem solving in algebra is close to the current practice in schools. Kikora follows largely the course found in standard textbooks, with the presentation of tasks and structures to solve them. The students are presented one task at a time. To answer the tasks, they use a specialized panel that may resemble buttons on a calculator with the basic arithmetic operators as well as square root, exponent, parentheses, and more (Figure 1).

When submitting an answer, the students get immediate feedback. This also applies to intermediate steps in the calculation as they enter the answers to such steps. By clicking a button, the students can ask for a hint for the next step in the calculation or the whole process of solving a problem. A correct submitted answer (or intermediate step) results in a green check mark, whereas an incorrect answer results in a red 'x'. When finishing a subchapter within a mathematical theme, they receive congratulations, and when finishing a theme, they get a "trophy".

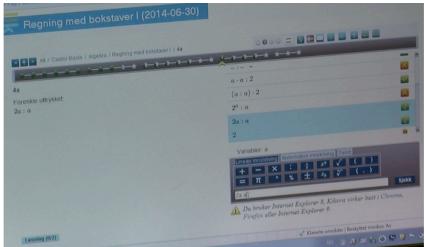


Figure 1. A screenshot of Kikora. The task is in the upper-left corner, and the 'hint' button is in the lower-left corner. The intermediate steps are shown above the specialized panel on the right.

DragonBox (Algebra 12+)

DragonBox is an award-winning game about algebra. In the game, running on tablets, students can manipulate elements in an equation through specific rules. The rules change slightly during the game depending on the students' progress. As they progress, the equations become more advanced, and new rules are introduced and visualized as new capabilities for interaction. The symbols also develop from figurative to more mathematical. In the beginning of the game, the symbols look like fish, insects, or dice (Figure 2); at the end of the game, there are equations with x, constants, numbers, and mathematical symbols.

The game consists of two large fields corresponding to the two sides of an equation, along with a storage located underneath consisting of objects that can be pulled out and placed within the two fields. The game is organized into chapters with increasing difficulty. A level ends when the main symbol—the dragon box (and later an "x")—stands alone in one field. Other evaluation criteria are whether the player has used the correct number of steps and whether there is an excessive number of objects in the other field that could have been eliminated. The player gets feedback on whether the criteria for successfully solving a level are met by getting one, two, or three stars.

An object can be moved into a field and inside an equation in accordance with the four basic arithmetic operations. It may add to or subtract from a side in the equation depending on how the student has assigned a plus or a minus sign to the object in the store, act as a multiplier when placed beside another object in a field, and act as a divisor when it is placed beneath an object and thus creates a fraction bar or a multiplication of an existing divisor.

When an object is drawn into a field, algorithmic rules are activated. When the player adds or subtracts an object on a field (one side of the equation), a dent appears in the other field (the other side of the equation),

which shows that a corresponding object should be placed there. The student cannot progress further in the game until the dent has been filled with a corresponding object.

In terms of game-based learning in school, Kikora and DragonBox represent two different approaches. Although Kikora offers rewards, it is close to standard algebraic notation and practices for problem solving found in textbooks. DragonBox offers a different approach to algebra compared to textbooks and Kikora. The aspect of gameplay in DragonBox is evident, and it can be seen as an example of stealth learning (Ke, 2008; Prensky, 2001) because some of the known difficulties of algebra are deliberately hidden. The students are presented with algebraic rules but mainly through direct manipulation of nonmathematical symbols. Through a point system and levels, the game gradually moves toward more standardized mathematical symbols. The students also participate in this "translation" through gameplay, and potentially they will see the rules and symbols as expressions for algebra.



Figure 2. A screenshot of DragonBox.

Method and setting

We observed a class of 75 students in eighth grade (age 13–14) who worked with algebra through a 4-week period (total of 8 clock hours). The class of 75 students was divided in two; one group used DragonBox in their group, and the other used Kikora. A pretest and a posttest just before and after the trial documented the students' performances in algebra. We conducted a video observation of whole class instruction and of four pairs of students (two pairs in each group), which were followed throughout the process. About half of the time was spent on plenary teaching, and the rest of the time was spent on work in pairs with the digital learning resources. The plenary teaching for the two groups was conducted by the same teacher and was virtually identical. The identical arrangement between the two groups of the class provided opportunities to examine the different conditions and outcomes provided by the use of the two digital learning resources, Kikora and DragonBox.

Our fieldwork resulted in about 25 hours of video material, where about 12 hours related to plenary sessions and about 10 hours showed students working in pairs with either Kikora or DragonBox. We also did interviews with eight students and the teacher, which resulted in about 3 hours of video material. By analyzing field observations, field notes, and video material (Derry et al., 2010), we looked for similarities and variations that emerged from the tests. We identified typical examples of conversations and activities in the interactions between pairs of students, with their teacher, and with the technology. Two examples are presented below. Detailed qualitative analysis of the activities and conversations related to the identified variations found in performance of the tests may give researchers a robust understanding of how the technologies create different conditions for meaning making and social interaction among students and their teacher in the classroom (Dolonen & Ludvigsen, 2012).

Results

Pretests and posttests

To find a variation of learning outcomes during the process, we carried out a test before students began their algebra course and a similar test afterward. The tests were developed with the teacher and were based on the national curriculum targets, the textbook, and TIMSS items (the latter as identified by Naalsund, 2012). The pretest showed negligible differences between the two groups of the class. Each of the 8 questions gave 0-2 points so that the maximum of possible points was 16.

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	Pretest Mean Scores (standard deviation)	Posttest Mean Scores (standard deviation)	Mean Performance Increase
Kikora group	5.17 (2.01)	9.91 (2.43)	4.74
DragonBox group	5.21 (3.36)	7.76 (3.66)	2.55

As Table 1 shows, there was a relatively large variation in performance between the group of students who worked in pairs using Kikora and the group of students who worked in pairs using DragonBox. Using a paired t-test for each group, the variations in performance from pretest to posttest are statistically significant (p <0.01) for both. Using an independent t-test on the variation in performance between the two groups on posttests only is also statistically significant (p <0.01). The teacher and one researcher did the scoring with an inter-rater reliability score of 0.918 using Fleiss's kappa (95.4% pairwise agreement). Thus, we can argue that both groups showed significant performance increase from pretest to posttest, but that the Kikora group increased significantly more than the DragonBox group.

To give an example of this variation, question 2 in the tests instructed the students to write the expression 3x + 2x + 6x (in pretest) and 2x + 3x + 8x (in posttest) as simply as possible. Related to this question, the mean improvement in performance for the DragonBox group was 18 percentage points (from 12% to 30% of maximum value), while Kikora students had a mean improvement in performance of 51 percentage points (from 20% to 71% of maximum value).

The significant variation in performance on the tests was surprising to us for three reasons. First, both groups spent 4 hours in plenary sessions in the 8-hour course with the same teacher and identical teaching. Second, we observe that students who used DragonBox expressed far more engagement along the way by enthusiastic discussions with each other as well as intensity in usage patterns. Observations of gameplay show that in DragonBox the students do not have to write expressions in order to solve equations. The students have a storage with a limited amount of appealing objects that fast and easily can be dragged and dropped unto and within the game board. In contrast, to solve an equation in Kikora the students have to write an expression with formal math symbols in a calculator, and check if the answer is correct. If the answer incorrect the students must rewrite the expression in the panel. As a result, the DragonBox group also spent more time using the learning resource by being far less distracted and doing off-task interactions than the Kikora students did. Third, the technology was timely beneficial for the DragonBox group because they worked on tablets while the Kikora group used laptops. The tablets were faster to start up than laptops, where much time was spent on plugging the machines in, starting them up, and getting them connected to the Internet. Easier startup gave the DragonBox students working in pairs almost an hour (58 minutes) more time on task compared to the Kikora students working in pairs. These reasons made us analyze what happened in the process between the two tests, and we focused on situations where students worked in pairs with the learning resources.

Interactions when using Kikora and DragonBox

From observations and video material from the plenary sessions and video of selected pairs of students, we analyzed the processes of student interactions in the algebra course. In general, we observed that the work in pairs was goal directed in both groups, and transcripts of the video recordings show that students discussed with each other and their teacher, and such discussions were aimed at both problem solving and technology use. However, the students and their teacher show variations in talk and interaction when using Kikora and DragonBox. We will now present short excerpts, one from a pair using Kikora and another from a pair using DragonBox. They are selected as typical examples of interaction between students working in pairs and their teacher when discussing mathematical concepts using their digital learning resources. In the first excerpt, we observe the two girls, Irene and Anne, trying to simplify the fraction 2a / a in Kikora. The teacher who walks around guiding pairs has just arrived at their desk:

1.	Irene:	Uhm If we take 2
2.	Anne:	Raised by
3.	Irene:	2
4.	Anne:	Isn't that a? (They get the wrong answer.)
5.]	Irene:	No. That was wrong. (Here they click the "hint" button in Kikora and get the answer: 2.)
()		
6. 1	Irene:	Only 2?
7. 7	Teacher:	Mmm. (confirming)
8. 4	Anne:	Yes, but how can that be correct?
9. 7	Teacher:	You can If you set it up You could use the paper notebook.
10. 4	Anne:	We have it.
11. 7	Teacher:	If you use a fraction bar, then you can write it as "2a" and then the fraction bar and then the "a" underneath it. Agree?
12. 4	Anne:	Yes.
13. 7	Teacher:	Mmm (confirming). If you have the paper notebook
14. 4	Anne:	Yes that's correct but (opens her paper notebook)
15.	Irene:	(With the keyboard looking at the teacher) Ok, now I've written
16. 7	Teacher:	<i>(Addressing Anne and her paper notebook).</i> Now, it is possible to shorten a bit when you are dealing with fractions.

This excerpt starts with the students using an exponent to solve the fraction. Having requested a response from Kikora, they are quick to conclude that using an exponent is not correct (line 5). The unexpected answer challenges them (lines 6 and 8), and the teacher recommends that they use the tools they know—paper and pencil—and calculate using a paper notebook (lines 9 and 13). He guides them through the work of setting up the fraction, refers to shortening fractions as a method (and a concept) (line 16), and since they already have the solution given by Kikora, they eventually find the procedure to correctly solve the problem.

By setting up the fraction with a traditional fraction bar and mentioning the concept of shortening a fraction, the teacher provides the students with tools that are close to a repertoire of problem solving they already know. The teacher attempts to bridge the representation of the problem in Kikora and how it can be represented and processed using a paper notebook. Thus, the teacher is able to guide them in the right direction by using multiple representations that are close to the students' cultural and historical practices. The episode indicates that the total picture of guidance by a teacher using concepts and standard notation in algebra through culturally well-known aids such as paper notebooks together with Kikora showing the answer provides a developmental zone that brings the student from an incorrect procedure using exponents to an understanding of the method that will produce the correct answer. We observed this repeatedly for pairs using Kikora.

Now, let's turn the attention to an excerpt in which students use DragonBox. It exemplifies what we observed when students used the game in the classroom. In the excerpt, the students try to solve an equation in which the dragon box (representing the unknown in standard algebra) is under a fraction bar in the right-hand field by eliminating a black fish symbol above the fraction bar. When a white fish symbol is dragged from the store and laid on the black fish symbol, it is eliminated and turns into a dice with one dot (representing the number 1).

1.	Teacher:	Remember what you did when you wanted to, in a way, move and change <i>(points at the symbols in the expression in the right field)</i> to make things appear in other places.
2.	Ellie:	Yes but When we do it becomes like a circle or a dot.
3.	Lilly:	Dice.
4.	Ellie:	Dice, yes, with one dot.
5.	Teacher:	Mmm. (confirming)
6.	Ellie:	And then there appears another one. (It is the mechanism that shows that they had to add a similar dice to the left field in order to balance the equation.)
7.	Teacher:	Yes.

8.	Ellie:	And then it won't go away.
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9. Teacher: No.

10. Ellie: No. (both girls laugh) Uhm...

11. Lilly: Should we just try something like this then? (*The girls try to move some symbols from the storage to both fields, but they seem helpless.*)

In this episode, the teacher tries to apply a mathematical concept in algebra that he knows the students know (line 1: "move and change" is a local concept for changing the sign of an integer when moving it from one side of the equation to the other). Later, however, neither he nor the students use standard math concepts such as fraction bars or numbers as we observed when using Kikora. For example, they do not talk about "the sides of the equation" that must be subjected to the same operations, which are relevant here. DragonBox has a symbolic language and problem-solving methods that represent a new world of mathematics for students and teachers. This mathematical world transforms gradually into more formal symbols and methods, as we know them from standard textbooks. The variety of symbols and methods for each task and each level makes it difficult for students and their teacher to be precise in their use of concepts when talking math. The teacher utters "things" (line 1), the students "like a circle" (line 2: a circle looking like a portal represents the 0 symbol in the game often used in addition and subtraction), "dot" (line 2), and "dice" (line 3). Eventually, we see that the teacher goes over to short utterances such as "Yes" or "No" (lines 5, 7, and 9), suggesting that he struggles to create a developmental zone for the pair. The field observations we made also suggest that some of the students, but not all, enter into a game-like mode characterized by unreflected trial and error. The students and their teacher do not use established practices in mathematics when they use DragonBox. The excerpt, which was representative of how the teacher guided students working in pairs, suggests that this symbolic world is difficult to talk about conceptually and is not easily transferred to paper notebooks or the whiteboard.

Discussion

Our aim with this mixed-method study is to contribute to the research and debate on game-based learning in classrooms. Our first research question concerns whether we can identify any variation in engagement and learning outcome when students use the two digital learning resources for algebra: a digital algebra game (DragonBox) and a web-based learning resource (Kikora). Our results show that there were obvious variations in student engagement and the results achieved using DragonBox and Kikora. The pairs using DragonBox showed a high degree of involvement and enthusiasm, almost continuously. It is rare to observe in mathematics classrooms that all students remain focused throughout the school hour and even in some cases want to work on longer. In contrast, the use of Kikora was not very different from ordinary problem solving in mathematics classrooms with paper and pencil, and it did not create any particular engagement or enthusiasm. Thus, it is surprising that the variation in learning outcomes as measured in tests was strongly and significantly in favor of pairs working with Kikora, although they were far less engaged and used less time on tasks.

Our second research question concerns how the two digital learning resources create different conditions for meaning making and social interaction among students and their teacher in the classroom. In this study, we observe how Kikora and DragonBox made possible but also constrained the interactions among students, their teacher, and the technology. The symbols and methods of problem solving applied in DragonBox did not support students and their teacher in terms of the formal language that exists for algebra, which is what is tested at school. Both the students and their teacher struggled to apply their repertoire for mathematical language using DragonBox, thus the teacher was unable to orchestrate a developmental zone between the students' existing knowledge and concepts and forms of symbolic interactions in DragonBox. Instead, the students' problem-solving were characterized by trial and error, indicating guessing and lack of direction. In Kikora, however, the teacher could apply a well-known mathematical language and a repertoire for helping students when they were struggling, but the learning resource did not add much compared to regular exercises in algebra.

This study has both practical and theoretical implications. In terms of practice, this study highlights the debate about the possibilities for using games in schools. The challenge is to design games that not only make students better at playing games but that also may be included in a school context and promote school-relevant learning. One aspect is that there is an inherent tension between the voluntary element of gaming and the involuntary element related to school. Another aspect is that the introduction of new games with novel symbolic worlds can create practical problems for teachers wanting to guide their students into algebra. It takes time to master a novel symbolic world and make it relevant in a school context. Theoretically, this study does not strengthen the DragonBox approach to algebra learning, which can be categorized as stealth learning (Habgood & Ainsworth, 2011; Ke, 2008; Prensky, 2001). The game provides engagement, but the results suggest that

symbolic interaction in the game constrains the participants' use of a well-known mathematical repertoire. Although students potentially learn a practice in and through DragonBox, it does not fit in terms of the school's practice of algebra. Further, this study also shows how important it is to go beyond reporting statistical effects of a practice. When we analyze the interaction of the participants, we may observe the aspects that create opportunities and constraints when participants try to make meaning out of technology and make it relevant for the context they are in (Silseth, 2012).

To conclude, this study addresses the debate and research of games in schools. It has been argued that it is important for the teacher to be able to bridge the gap between engagement in gameplay and curriculum goals (e.g., Habgood & Ainsworth, 2011; Young et al., 2012). However, to do so, it is important to understand that a game and a school are potentially two different activity systems, often with different symbolic interactions and purposes, which make it challenging for students and teachers to make meaning out of the game that is relevant to the school's norms for what it takes to know a discipline.

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Looking AT versus Looking THROUGH: A Dual Eye-tracking Study in MOOC Context

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Abstract: We present an eye-tracking study to show the different gaze patterns across the MOOC learners. We hypothesize that the pretests can be used to shape the attention of the students. Moreover we also proposed a collaborative add on activity to the learning material for the students to help them reflect on the material they learnt in the MOOC video. What comes out of the present study is two different interaction styles that differentiate the good students from the poor students. The good students engage with the teacher/collaborating partner through the interface/display. While the poor students engage with the material only. We name these two interaction styles as "looking through" and "looking at" respectively.

Keywords: Eye-tracking, massive open online courses, student engagement

Introduction

In the last two years millions of students worldwide have signed up for Massive Open Online Courses (MOOCs). The major issues for the MOOC researchers are: "how to develop efficient measures to capture the attention and engagement of the students?" and "how to make the learning process more efficient?" We address these two questions using a dual eye- tracking study based on a MOOC lecture and other add-on activities. Before the students attend to the MOOC lecture we use a pretest to prime them about the course content and after they have watched the video we ask them to collaboratively create a concept map based on what they learnt in the MOOC lecture.

We capture the attention and engagement of students during the video lecture and during the collaborative activity using eye tracking. In the present decade, off the shelf eye-trackers have readily become available. Soon the eye tracking will no more only be a sophisticated research tool.

In this article we present an empirical study that sheds some light on the gaze features of the MOOC learners and the effect of priming the students in two different ways. As we will see, the priming method impacts the learning gain of the students; and the gaze features we propose are efficient enough to highlight the differences between the good MOOC learners from the poor ones.

The two main contributions of the paper are as follows. First, we distinguish between the categories of learners based on how efficiently the students use the display to connect to the teacher or their peers. Second, we validate our gaze measures for quantifying how much the student follows the teacher and how together the collaborating pair works.

The rest of this paper is organized as follows. The second section presents the related work from collaborative eye-tracking research and from eye-tracking research in online learning. The third section presents the salient features and research questions from the present study. The fourth section explains the experiment and it's variables. The fifth section presents the results. The sixth section discusses the implications of the results. Finally, the seventh section concludes the paper.

Related work

Eye tracking for online collaboration

In previous studies Jermann, et. al., (2010), Nüssli, et. al., (2009), have shown that the gaze is predictive of the expertise and/or the task performance. In a collaborative Tetris task, Jermann et al., (2010) showed that the experts focus more on the stack than the novices. In a collaborative Raven and Bongard puzzle solving task, Nüssli et al., (2009) showed that the good performers switch more often between the problem figures and the solution figures than the bad performers. Molinari, et. al., (2008) showed that the gaze is predictive of the mutual modeling of knowledge in a pair. The participants used a knowledge awareness tool, to assess their partners' knowledge, to manipulate their own actions on the concept map.

In a collaborative concept map task, Liu et al., (2009) used the gaze data to predict the expertise level of the pair. In a reference disambiguation task, Kraljic & Brennan, (2005) showed that the good performers spent less time on the ambiguous objects then the bad performers. In another collaborative problem solving task, Schneider (2013) showed that the gaze features are predictive of the collaboration quality (a rating scheme proposed by (Meier, Spada, & Rummel, 2007).

In a collaborative task the moments of joint attention are the most important. The moments of joint attention provide the basis of creating a shared understanding of the problem at hand. Making references is a key process to initiate a moment of joint attention. Jermann & Nüssli, (2012); Richardson & Dale, (2005) and Richardson, et. al., (2007) showed in the different studies how the moments of joint attention affect the gaze of the collaborating partners. The cross-recurrence (the probability of looking at the same thing at the same time) was observed to be higher during the referencing moments than rest of the interaction (Richardson & Dale, 2005; Richardson et al., 2007), Moreover, Jermann & Nüssli, (2012) showed that the pairs with high quality of interaction have higher cross-recurrence during the moments of joint attention.

Apart from moments of joint attention there are many other episodes of interaction during a collaborative problem-solving task. These episodes can be based on an underlying cognitive process (Aleven, et. al., 2012; Sharma, et. al., 2012) or dialogues (Gergle & Clark, 2011). In a pair program comprehension study, Sharma, et. al., (2012) showed that gaze patterns of the pair can differentiate between the episodes of linear reading and episodes of understanding the data flow of the program. In a collaborative learning task, Aleven et al. (2012) showed that the gaze patterns are indicative of the individual and collaborative learning strategies. In a pair programming task Sharma, et. al., (2012 and 2013); Jermann & Nüssli (2012) showed that certain dialogue episodes correspond to the higher gaze proportions at certain area on the screen. In a collaborative elicitation task, Gergle & Clark, (2011) showed that the movement of mobile partners can help them as a coordination mechanism.

Eye-tracking for online education

Use of eye-tracking in online education has provided the researchers with insights about the students' learning processes and outcomes. Scheiter, et. al., (2010) emphasizes on the usefulness of the eye tracking methods as analytical tools in online education and collaborative problem solving. Sharma, et. al. (2014 a, 2014 b) proposed gaze measures to predict the learning outcome in MOOCs. Sharma et. al. (2014a) uses the low level gaze features (derived from the stimulus) to predict the learning outcome; while Sharma et. al. (2014b) used the fact that how closely the students follow the teachers' deictic and verbal references to predict the learning outcomes. van Gog & Scheiter (2010) used eye-tracking to analyze multimedia learning process and instruction design. Scheiter, et. al. (2010) used eye-tracking data to differentiate between conceptual strategies in relation with different expertise levels in multimedia learning. Van Gog, et. al. (2005a) used eye-tracking data to differentiate expertise levels in different phases of an electrical circuit troubleshooting problem and concludes that experts focus more on the problematic area than the novices.

Mayer, (2010) summarized the major eye-tracking results on online learning with graphics and concluded that there was a strong relation between fixation durations and learning outcomes and visual signal guided students' visual attention. In a study to compare the affect of color coded learning material Ozcelik, et. al., (2009) found that the learning gain and the average fixation duration were higher for the students who received the color coded material than those who received the non color coded material.

Present study

We present a dual eye-tracking study where the participants attended a MOOC lecture individually and then a pair of participants collaborated to create the concept map about the learning material. We use the pretest to shape the understanding of the participants in a specific way (paying more attention to textual or schema elements in the video). This is called priming effect. One of the major hypothesis is that the there are two factors shaping the learning gain of the students: 1) how closely the students follow the teacher? 2) how well they collaborate in the concept map task? The first factor is important because the more a student follows the teacher, the more he could learn. The second factor is important because the better a student collaborates with the partner, the more the pair could discuss the learning material and have a better understanding. The present contribution explores the following research questions:

Question 1:How does the priming affect learning? We want to see if there is a priming
effect on the learning gain of the participants .Question 2:How are the individual gaze patterns during the video related to the

Question 3: How are the individual and collaborative gaze patterns related to learning gain?

Experiment and methods

Independent variables and conditions

We used a pretest as a contextual priming method. We designed two versions of the pretest. The first version had usual textual questions. The second version had exactly the same questions as in the first version but they were depicted as a schema (Figure 1 (a)).

Priming condition

Based on the two priming types we had two priming conditions for the individual video lecture task: 1) textual priming and 2) schema priming.

Pair composition

Based on the two priming types we had three pair compositions for the collaborative concept map task: 1) Both the participants received the textual pretest (TT); 2) Both the participants received the schema pretest (SS); 3) Both the participants received different pretests (ST).

Participants and procedure

98 students from École Polytechnique Fédérale de Lausanne, Switzerland participated in the present study. The participants were paid an equivalent of CHF 30 for their participation in the study. There were 49 participants in each of the priming condition (textual and schema). There were 16 pairs in each of TT and SS pair configurations while there were 17 pairs in ST pair configuration.

Upon their arrival in the laboratory, the participants signed a consent form. Then the participants took an individual pretest about the video content. Then the participants individually watched two videos about "resting membrane potential". Then they created a collaborative concept map using IHMC CMap tools¹. Finally, they took an individual posttest. The videos^{2,3} were taken from "Khan Academy". The total length of the videos was 17 minutes and 5 seconds. The participants came to the laboratory in pairs. While watching the videos, the participants had full control over the video player. The participants had no time constraint during the video phase. The collaborative concept map phase was 10 minutes long. During the collaborative concept map phase the participants could talk to each other while their screens were synchronized, i.e., the participants in a pair were able to see what their partners' action. Both the pretest and the posttest were multiple-choice questions where the participants had to indicate whether a given statement was either true or false. The gaze was recorded using the SMI RED 250 eye-trackers.

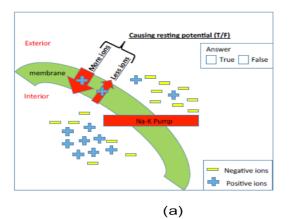
Dependent variable: Learning gain

The learning gain was calculated simply as the difference between the individual pretest and posttest scores. The miming and maximum for each test were 0 and 10, respectively.

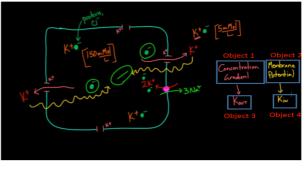
Process variables

With-me-ness during the video lecture

With-me-ness (Sharma et. al., 2014b) is a gaze measure for quantifying students' attention during the video lectures. With-me-ness has two components: 1) perceptual with-me-ness and 2) conceptual with-me-ness. The perceptual with-me-ness captures the students' attention especially during the moments when the teacher makes explicit deictic gestures. Whereas, the conceptual with-me-ness captures whether and how much the gaze of the student is following the teacher's dialogues. To compute conceptual with-me-ness, two authors mapped the teachers' dialogues to the different objects on the screen. We name these objects as objects of interest (figure 1 (b)). Once we have the objects of interest on the screen, we computed what proportion of gaze time to the dialogue length (+2 seconds) in time is spent by the participants on the objects of interest. This proportion is the measure of the conceptual with-me-ness.



Teacher: "so you have one force, the concentration driving K out; and another force the membrane potential, that gets created by its absence that's gonna drive it back in."



(b)

Figure 1. (a) Example question from the schema version of the pretest. The corresponding question in the textual version of pretest was "The original cause of the resting potential is the fact that the amount of the positive ions which diffuse to the interior is slightly more than the amount of the positive ions which diffuse to the exterior. (TRUE/FALSE)". (b) Example of objects of interest from the video lecture used in the experimental task. The example shows the four objects, related to the teacher's dialogue, on the screen.

Gaze similarity during collaborative concept map

The gaze similarity is the measure of how much the two participants in a pair were looking at the same thing at the same time (figure 2) or how similar their gaze patterns were during a short period of time. To compute the gaze similarity the whole interaction (during the collaborative concept map task) is divided into equal duration time windows. For each time window we compute a proportion vector, for each participant, containing the proportion of the window duration spent on each object of interest on the screen. Finally, the gaze similarity is computed as the scalar product of the proportion vector for the two participants in a pair. The gaze similarity is a similar measure as the cross-recurrence proposed by Richardson & Dale, (2005) but it is easier and faster to compute.

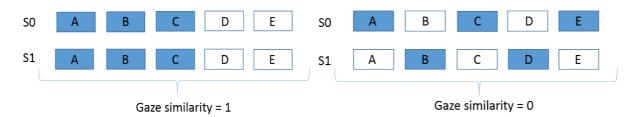


Figure 2. Typical cases in calculation of gaze similarity the filled rectangle denotes that the there was some time spent on the labeled object and the empty rectangle shows that there was no gaze on that particular object. If there are 5 objects (A, B, C, D, E) on the screen and the two participants (S0 and S1) are looking at the objects. The case with gaze similarity 1 shows that in a given time window both the participants spent equal amount of time on the respective objects. The case with gaze similarity 0 shows that in a given time window both the participants were looking at completely different sets of objects.

Results

The results show the relation between the priming, the two levels of with-me-ness during video phase, the gaze similarity and the learning gain. A fact that is worth mentioning at this point is that the time on task during the video lecture phase was varying across the participants. However, we do not observe a significant relation between the time spent on the video and the learning gain. For this contribution we are only focusing on the relation between the gaze patterns of the students during the video lecture and the collaborative concept map.

Priming effect on the learning gain

We observe a significant difference in the learning gain between the two priming conditions (figure 3a). The learning gain for the participants in the textual priming condition is significantly higher than the learning gain for the participants in the schema priming condition (F [1, 96] = 16.77, p < .01).

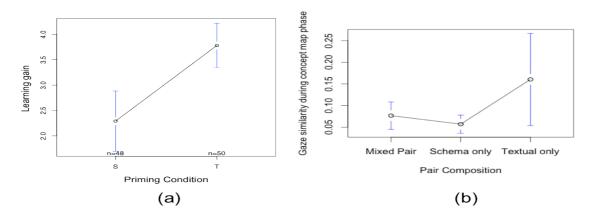


Figure 3. (a) Learning gains for the two priming conditions. (b) Gaze similarity for the three pair compositions

Pair composition and gaze similarity

We observe a significant difference in the gaze similarity be- tween the three pair configurations (figure 3b). The learning gain for the TT pairs is significantly higher than the gaze similarity for ST or SS pairs (F [2, 46] = 3.44,

With-me-ness and gaze similarity

Perceptual with-me-ness

We observe a significant positive correlation between the gaze similarity and the average perceptual with-meness of the pair (r(47) = 0.48, p < .01). The pairs having high gaze similarity have high average perceptual with-meness.

Conceptual with-me-ness versus gaze similarity

We observe a significant positive correlation between the gaze similarity and the average conceptual with-meness of the pair (r(47) = 0.34, p < .05). The pairs having high gaze similarity have high average conceptual with-meness.

With-me-ness and learning gain

Perceptual with-me-ness

We observe a significant positive correlation between the perceptual with-me-ness and the learning gain (r(96) = 0.51, p < .01). This difference is irrespective of the priming condition. The participants having high perceptual with-me-ness, irrespective of their priming type, have high learning gain.

Conceptual with-me-ness

We observe a significant positive correlation between the conceptual with-me-ness and the learning gain (r(96) = 0.41, p < .01). This difference is irrespective of the priming condition. The participants having high conceptual with-me- ness, irrespective of their priming type, have high learning gain.

Gaze similarity and learning gain

We observe a significant positive correlation between the gaze similarity between the pair and the learning gain (r(96) = 0.39, p < .05). The pairs having high gaze similarity have high learning gain.

Discussion

The research questions we addressed through the present study were about the relationships among the priming, the learning gain, with-me-ness during the video and the pair's gaze similarity during the collaborative concept map task. In this section we present the possible interpretation of the results presented in the previous section.

The first question concerns the effectiveness of priming on the learning gain of the participants. The learning gain of the participants in textual priming condition is significantly higher than that for the participants in the schema priming condition.

Moreover, during the collaborative concept map task, the pairs with both the participants from the textual priming condition have higher gaze similarity than the pairs in other two configurations (both from schema priming condition and both from different priming conditions). Once again, we can expect a better priming effect in textual priming condition than in the schema priming condition. The second question we address is about the relationship between the gaze patterns of the participants during the video watching phase and during the collaborative concept map phase. The pairs having high average with-me-ness also have a high gaze similarity. This is explained in terms of sharing a strong basis for shared understanding of the topic. Sharma et. al. (2014b) also found that with-me-ness is correlated with the learning outcomes. If both the participants followed the lecture in an efficient manner, i.e., with high with-me-ness, the pair has a strong base to build a shared understanding. Hence, the pair has more gaze similarity. This result is also consistent with the related research by (Richardson & Dale, 2005 and Richardson, et. al., 2007) where the gaze cross- recurrence is higher when the participants had a better level of mutual understanding.

The first part of the third question address the effect of the with-me-ness on the learning gain. Both the levels of with-me-ness are positively correlated with the learning gain, which is consistent with the results found by Sharma et. al. (2014b). The only difference is that in the present study we observe higher values for both the perceptual and conceptual with-me-ness than what Sharma et. al. (2014b) found in their experiments. The different levels of with-me-ness values are explained by the different types of the video lecture. The video used by Sharma et. al. (2014b) had only textual slides. The video in the present experiment had no slides; the teacher starts with a blank board and incrementally fills the board by writing the lecture material (schemas, tables, formulas). The low values of the correlation in the experiment can be explained by the nature of the videos. In the video from Sharma et. al. (2014b), the content is present on the screen from the beginning of slide resulting in the distraction as students might start reading from the slides and do not listen to the teacher. On the other hand, the video content in the video of the present experiment itself follows the flow of teacher's discourse hence resulting in higher values of with-me-ness for every student.

Finally, the second part of the third question inquires about the effect of the gaze similarity during the collaborative concept map task on the learning gain. The pairs with high gaze similarity also have high average learning gain. This can be explained using the fact that the high gaze similarity indicates a good shared understanding on the concerned topic. Hence, a similar pair (in terms of gaze) discusses the lecture points in a better manner than the pair with low gaze similarity. More specifically, the pair with high gaze similarity works on the same part of the concept map in a given time window, hence they develop a better mutual understanding about the concerned topic. Whereas, the pair with low gaze similarity work on less similar parts of the concept map and hence they fail to have a shared understanding.

Conclusions

We have studies the gaze properties of a learner during a MOOC lecture and during a collaborative concept map task. The good learner follows the teacher in both the perceptual and conceptual spaces of teacher-student interaction. More- over, a good learner is also well synchronized with his/her partner during a collaborative task. We also explored the effect of priming on the learning gain and the gaze patterns of the students. We observe that the textual priming has some advantages over the schema priming. A plausible explanation for textual priming emerging out as the better way of priming, as far as learning gain is concerned, is that the students are more used to the text than the schema tests in their regular studies. However, the effects of the textual priming on the collaborative gaze patterns might be attributed to the fact that textual priming has better effects than the schema priming.

From the present study, what emerged as a working hypothesis for the future research is a concept of "looking through" versus "looking at": some learners look "at" the display, as we look at a magazine, while other students seem to look "through" the display, that is, to look at the teacher or their partner in interaction as if they were actually present there. The latter seems to gain deeper engagement and hence a better learning outcome. The students who look "at" the display lag in following either the teacher or their partners. Whereas, the students who look "through" the display, use the display not only to follow the teacher or their partner but they use the display to create a shared understanding. Having a shared understanding in tern increases the learning gain for such students.

The concepts of "looking through" and "looking at" could be seen as new interaction style categories. "Looking at" the interface/ display indicates that the person is engaged with the material only, which is presented to him/her. "Looking through" the interface/ display indicates that the person is en- gaged with the peer. The peer in the video phase is the teacher and in the collaborative concept map is the collaborating partner. The "looking through" interaction resembles the social colocation of the interacting peers. As an analogy, to high- light the difference between the two interaction styles, we can compare the interaction with the teacher/collaborating partner to watching a movie. "Looking at" can be compared with liking the movie; whereas, "looking through" can be compared with appreciating the director.

Finally, we also validate the gaze measure for following the teacher during the MOOC lecture. We observe that the with- me-ness is a gaze measure that can be calculated for any kind of lecture independent of the lecture type. We also observe the consistency of the relation between the with-me-ness and the learning outcomes across the present study and our previous work (Sharma et. al., 2014b). Moreover, we also validate the collaborative gaze measure "gaze similarity" is a simpler and yet equally efficient measure to another mostly used collaborative gaze measure cross-recurrence (Richardson & Dale, 2005 and Richardson, et. al., 2007).

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How Learners Employ Semiotic Resources for Collaborative Meaning-Making in Outdoor Mobile Learning

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Abstract: This paper attempts to investigate how learners employ semiotic resources present in the material and physical world to construct and to negotiate shared meanings in an outdoor mobile learning context. We investigate the collaborative meaning-making and interaction process of two groups of 13-year-old students (Grade 7) during an outdoor mobile learning trail exploring the history and geographical features of World War II battle site. Methodologically, we employ video-based interaction analysis, which facilitates a micro-level analysis of human interaction, to understand how learners deploy and assemble the material and social resources available in the outdoor learning context. We surface two noteworthy patterns about a) how learners in small groups leverage semiotic resources to negotiate, repair and converge at shared meaning in changing contextual configurations and b) how prior learning experiences affect the way learners employ semiotic resources. The findings provide helpful insights into the design and implementation of mobile learning activities in outdoor settings.

Introduction

In recent years, researchers, key stakeholders, school leaders and practitioners alike, recognize the growing significance of the borderless classroom and the emergence of mobile learning as legitimate learning platforms. Hitherto, the rich repertoire of research and literature on mobile learning revolves chiefly around exploring emerging mobile devices and Web/cloud technologies to enhance learning experience across physical locations. On the other end of the spectrum of research on mobile learning, research studies caution against an obsessive focus on the technological system and the naive assumption of learning anytime and anywhere (e.g., Eliasson, Nouri, Cerratto Pargman & Ramberg, 2010; Frohberg, Göth, & Schwabe, 2009). They accentuate the importance of positioning mobile learning as socio-cultural activities and the criticality of designing learning activities that indeed foster both physical interaction with multiple resources available in physical environments, and social interaction supported through the mediation of mobile technologies (Kerawalla et al., 2012; Pachler, Bachmair, & Cook, 2010). Also, there appears to be a dearth of previous research work, which explores the intricate and the interwoven nature of the collaborative meaning-making process, not only between and amongst learners, but also with the *physical and the material world* in an outdoor mobile learning context. However, there remains a dire need for researchers and educators to investigate the dynamics at play in an outdoor mobile learning context, which have significant bearings on mobile learning design and implementation.

To unpack the complex meaning-making processes in an outdoor mobile learning context, this study addresses the question of how learners employ different kinds of semiotic resources present in the material world to construct and negotiate meanings within the context of collaborative mobile learning. While scholars accept the importance of unpacking the interplay of multiple resources during mobile learning, performing indepth analysis of meaning-making process is methodologically challenging. Thus, we employ video-based interaction analysis (Jordan & Henderson, 1995) to explore this rich-textured experience and interaction at both verbal and nonverbal levels in an outdoor mobile learning environment. Essentially, through the use of video-based analysis, we want to answer the research questions regarding (a) how learners employ the multiple semiotic resources (e.g. artefacts, social resources) in the physical, social and material realm to negotiate, repair and converge at shared meanings, and (b) how prior learning experiences affect the way learners employ semiotic resources in an outdoor mobile learning context.

Theoretical framework

Mobile learning as situated activity in a physical and social context

The notion of mobile learning has been fraught with diverse views and definitions of what 'Mobile Learning' connotes and how it ought to take shape. Some conceptual frameworks of mobile learning underscore the works of Lave and Wenger (1991) on the *situated nature* of learning, where they conceive of "knowing as activity by specific people in specific circumstances" (p. 52). Vavoula and Sharples (2008) accentuate that mobile learning

is essentially about learning in context and pervasive learning across different contexts. Similarly, Pachler et al. (2010) emphasize the situated interpretative nature of mobile learning that mobile learning experiences enable learners to "reinterpret their everyday life contexts as potential resources for learning. Learning is viewed as *semiotic work* and *meaning making* in which users develop, with the aid of devices, new cultural practices with and through which they learn and strengthen *their resources for meaning-making* whilst interacting with the world" (p. 5, emphasis added). In this light, the focal point of mobile learning would be to maximize the presence of a real world platform, engaging learners in semiotic work with relevant resources for meaningful knowledge creation and production where "the process of learning is informed by sense of place" (Lim & Barton, 2006).

In this research, we contend that there is a critical need to shift from technology-driven mobile learning design to one that supports semiotic work and situated learning experiences leveraging on physical affordances of environment, and importantly, giving focus to the dynamics and synergy of collective cognition in mobile learning. In Frohberg, Göth and Schwabe's (2009) critical review of mobile learning projects, they caution against embracing the general perception of mobile learning as learning anytime, anywhere with compact mobile devices. Mobile devices should be seen as mediating tools that allow people to capitalise on the situation in terms of the immediate physical space, while promoting social interaction that enhances the learning context.

Collaborative meaning-making and semiotic resources

The process of collaborative meaning-making is poignantly illustrated by Stahl's (2005) notion of a "shared meaning and common ground" constructed through group discourse in the context of a joint activity, where he contends that the "status of this shared meaning must be continually achieved in the group interaction"; frequently the shared status of 'breaks down' and repair is necessary" (p. 345). In mobile learning scenarios, the 'context' of a shared activity cannot be fully pre-specified, since the repair and re-conceptualisation of meaning-making is created through the situated activity of learning (Sharples, Taylor, & Vavoula, 2005). On the same note, Kerawalla et al.'s (2012) research on learners' interpretation of and interaction with the environment on a geography field trip showed that apart from the use of mobile technologies, learners had to leverage multimodal semiotic resources such as gesture, gaze, and bodily location in the meaning-making process. By semiotic resources, we are inclined to adopt van Leeuwen's (2005) definition of semiotic resources as actions, materials and artifacts for communicative purposes, which encompass both the physiological, as well as the technological realm. A semiotic resource is thus, a material, social, and cultural resource.

As aforementioned, the collaborative meaning-making process, therefore, inevitably involves trouble and repair among participants, making it necessary to realign with semiotic resources such as artefacts and social resources in the physical and material world to arrive at shared meanings. From the perspective of interaction analysis, when premeditated trajectory of activity is interrupted, it calls for more than repairs at the verbal level: it necessitates an analysis of how learners exploit *bodily*, *artifactual*, *spatial*, and *social* resources in the physical, social and material environment, to restore normalcy and resolve issues (Jordan & Henderson, 1995). For instance, in the video-analysis on how two students resolve technical difficulties in operating a machine, Roschelle and Clancey (1991) surface the notion of a "shared visual and manipulative space" where identifying the trouble and the solutions requires mutual alignment in this 'shared space'. Here, the two students engage a combination of 'talk', 'gesture' and 'screen objects' in this 'shared space' to arrive at a solution.

However, in a mobile learning context, the concept of a shared visual and manipulative space and the likelihood of stable situations may vary significantly. Here, it is helpful to visit Goodwin's (2009) postulation of *changing contextual configurations*. Goodwin (2009) contends that contextual configuration does not and cannot remain constant for "as action unfolds, new semiotic fields can be added, while others are treated as no longer relevant" (p. 21). This implies that the actions and thought processes experience a course of continual change as new semiotic resources enter and exit the context. Thus to this end, participation framework, interaction patterns and the building of action are subjected to the fluidity of contextual configuration specific to the moment and to that particular context. As such, participants alter their course of actions accordingly, to accommodate, to adapt to new configurations, and to realign with the emerging artifactual, spatial and social resources. Thus, our research questions aims to investigate the following:

- 1) How do learners employ the multiple semiotic resources (e.g., artefacts, social resources or spatial resources) in the physical, social and material realm to negotiate, repair and converge at shared meanings?
- 2) How do prior learning experiences affect the way learners employ semiotic resources in an outdoor mobile learning context?

Methodology

Research background and context

This research was carried out in one of the future schools in Singapore, which leverages on its 1:1 computing initiative to create a technology-rich learning environment. The research team worked closely with the collaborating teachers in the Integrated Humanity subject (i.e., history and geography) to design mobile learning activities that integrate knowledge, skills, and attitude to solve complex problems in authentic places. One particular platform of such mobile learning activities is what we called a *mobile learning trail*, conceptualized as a series of learning activities in and out of school mediated by mobile devices and applications.

In this paper, we discuss the implementation of a mobile learning trail titled *the British Defence Strategy Trail* that was designed for students to understand the fall of Singapore in World War II. The British Defence Strategy Trail took place at Fort Siloso, situated at the Western tip of Sentosa Island, Singapore, which is the site used by the British to defend Singapore during WWII. Fort Siloso was selected as a suitable location for this mobile learning trail for its historic significance during WWII, and for the availability of physical artefacts such as numerous tunnels, artillery guns and other resources left behind from the war.

Participants of the British Defence Strategy Trail were Secondary One (Grade 7, aged 13) students, who were acquainted with the use of interactive digital tools and mobile technologies both in and out of the classroom. We adopted a small-group collaboration structure where groups of 3-4 members were formed and remained in the same group throughout the trail. Regarding more specific design of learning activities, we first identified a BIG (Beyond Information Given) question that serves as an overarching inquiry goal that students pursue through various learning activities. Under a BIG question, we adopted a three-stage learning model that includes the integrated design of pre-trail lessons in the classroom, outdoor mobile learning trail and post-trail discussions in the classroom. Prior to the mobile learning trail, the students participated in History and Geography lessons to learn about the history of WWII and mapping/ navigation skills.

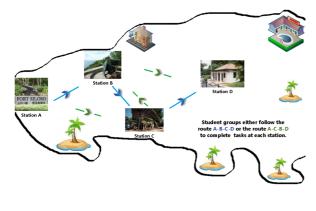
As shown in Figure 1, we identified four areas at Fort Siloso; what we called "learning stations" for the mobile learning trail. A series of trail tasks at the four learning stations (A to D) was designed to enable learners to answer the overarching BIG question on "What is the role of Fort Siloso at Sentosa Island in the British's big plan of defence to protect Singapore during WWII?" Various learning tasks at each of the four stations were designed for students to co-construct and to advance knowledge toward answering this BIG question. Table 1 presents an overview of the type of tasks designed for the British Defence Strategy Trail at learning stations A and C (for the focus of this paper). Trail tasks range from performative to knowledge generative. A *performative task* refers to a simple direct application task that is procedural, close-ended and linear leading to fixed answers. In a performative task, students are expected to apply knowledge and skills learned in pre-trail lessons in school to real-world contexts. On the other hand, a *knowledge generative task* is ill-structured, open-ended and non-linear leading to multiple potential answers. For instance, at learning station A, learners were first tasked to determine the direction of the gun using the iPad compass (Task 1: Performative), and thereafter, to locate the tunnel B and explain the purpose of the tunnel (Task 2: Knowledge Generative).

~	BIG Question: What is the role of Sentosa in the British's big plan of defence to project Singapore during WWII?				
Station	Task Type	Task Description			
Α	Performative	T1. Determine the direction of the guns using the iPad compass.			
	Knowledge Generative	T2. Describe the dimension of the tunnel and state its purpose			
	Knowledge	T4. Explain why the previous artillery gun (Area A) and this one are pointed in the same direction.			
	Generative	T5. Give reasons for the British's plan to locate the tower at Area B. Describe the role and purpose of the tower and the guns.			
С	Performative	T6. Calculate the distance between the cliff to Pulau Palawan (house food & ammunition supplies).			
	Knowledge	T7. Identify whether the vessel is "friendly" or "hostile" using the chart at			
	Generative	the watchtower.			
		T8. Give reasons for the erecting of another tower in this area. Describe the			
	Knowledge	role and purpose of the tower and the guns.			
	Generative				

BIC Question: What is the role of Sontase in the British's hig plan of defense to project Singapore

Table 1: Overview	of mobile	learning trai	l tasks a	t Sentosa	Island

On the use of mobile devices, students in small group (3-4 members) shared an iPad as a main mobile device to access the web-based platform called SquareCrumb that hosted all learning activities and associated mobile applications (see Fig 2). In this platform, the students could retrieve the learning tasks at each learning station, save their findings, data, and notes. They were able to interact with other group members and teachers through the synchronous broadcasting and feedback features.





<u>Figure 1.</u> Activity sequence and structure in the British Defence Strategy Trail

Figure 2. Learners leverage use of technological resources to find their bearing.

Data collection and analysis

We closely observed and monitored two small groups of four members each (Group 1 and Group 2 hereinafter) throughout the mobile learning trail. These two groups of students were audio- and video-recorded during the trail. Each student wore a small-sized audio-recorder, which recorded the dialogue of each group. One research assistant was assigned to each group to video record group interaction throughout the trail. Two researchers followed each group and took field notes. All video and audio recordings of participants' interaction discourse at the two learning stations (A & C) were formatted and transcribed respectively for analysis using the TransAna software. Stations A and C were selected for analysis owing to the range of task types and the physical and material context of the learning stations which aligns with the objective of this researchers who followed and observed the two groups, taking field notes were also the same researchers who conducted the video-based interaction analysis. Apart from individual analysis work, the two researchers engaged in "collaborative viewing" (Jordan & Henderson, 1995) to overcome the inclination towards partiality arising from predetermined conceptions and analyst bias. Further, in the collaborative viewing and discussion phase, field notes taken on day of event were also resurfaced to lend support and affirmation of analysis and findings.

The corpus of video data at the two learning stations was first segmentised according to larger, clearly defined events. These larger events were first, marked by the learning stations and next, by the different task types. Each of these larger events was then further segmentised into smaller units for analysis based on discursive moves, participation movements, interaction with the resources in the physical and the material space. Our data analysis was guided by a set of analytic foci in interaction analysis (e.g., turn-taking interaction, participation structure, artefacts and documents, trouble and repair) from Jordan and Henderson (1995).

Findings and discussion

In this section, we attempt to surface two noteworthy patterns from interaction analysis about how students in small groups leverage the use of semiotic resources in the material and physical world to construct and negotiate shared understanding:

- 1) How do learners employ the multiple semiotic resources (e.g., artefacts, social resources or spatial resources) in the physical, social and material realm to negotiate, repair and converge at shared meanings?
- 2) How do prior learning experiences affect the way learners employ semiotic resources in an outdoor mobile learning context?

Trouble and repair in changing contextual configuration

We investigated how learners leverage the use of semiotic resources to manage "trouble and repair" in an outdoor mobile learning setting, where the contextual configuration of semiotic resources in the physical and material world is unlikely to remain constant. The following interaction discourse (see Episode 1) illustrates how changing contextual configurations shape and structure the collaborative meaning-making process and how learners reassemble resources inherent in each contextual change, to negotiate conflicting perceptions and achieve collective goals.

Line	Student	Verbal	Nonverbal
1	Е	Eh the map is correct or not?	The team is walking towards what they believe is
2	Y	No, Gavin checking!	tunnel C. However, E appears uncertain about the digital map and G decides to move off to check if the tunnel ahead is indeed tunnel C.
3	Е	Huh? That one is tunnel A, we	E is still trying to locate tunnel C with the digital
4	G	Tunnel A	map. G calls out to them that it is tunnel A, not C.
5	Y	Tunnel B is there, then tunnel C is all the way there! See all the people there. Why you want to go there?	Y spots other teams heading in that direction and confirms that tunnel C should be on the other side.
6	E	Tunnel C is that way, cos erm, north is this way right, then north south, north east, north	E hands over the iPad to Y. She makes use of spatial orientation to affirm the team's current position and the probable location of tunnel C.
7	G	Check that map (referring to the Google map). Tunnel A, where's tunnel A?	G suggests to the team to check the map again.
8	Е	Isn't it showing south? Go!	The three of them review the map.
9	G	No not that direction. 24 So that means we suppose to go there. Opposite. That means go there la. Do we need to climb the stairs?	G studies the map and re-directs the team. On the way to the tunnel, E also makes use of the physical map & signage to affirm the location.

Table 2: Episode 1 – Group 2 in the process of locating tunnel C

The team was confronted with conflicting viewpoints owing to the different resources the members tapped on, coupled with some technical problems with the digital map. Here, the technological resource (i.e., digital map), the physical location map and the rich physical affordances of an outdoor setting (their spatial orientation with reference to their present physical location) offer differing information on the exact location of tunnel C (see Lines 1 to 7). On top of that, there was the availability of social resources (e.g., other groups) as point of reference (see Line 5). Learners were engaged in a process of what Roschelle (1992) construed of as an "iterative cycle of displaying, confirming and repairing meanings" where former conjectures give way to new meanings/ ideas based on new contextual configuration to another in 'trouble and repair' (Goodwin, 2009, p. 34), by reassembling resources to restore interaction and resolve difficulties. It also reiterates that establishing common grounds in shared meaning-making (Stahl, 2005) could only be achieved through mutual alignment in a 'shared space' (Roschelle & Clancey, 1991).

Another interesting phenomenon observed in this episode is how semiotic resources, in particular, the rich physical affordances of the outdoor learning context could impact seemingly straightforward task types. While application and procedural tasks are presumably easier as compared to tasks that require critical thinking and inferential skills, our analysis showed otherwise. Apparently, both groups at the learning station C spent considerable amount of time in completing the performative task (T6: Calculate the distance between the cliff to Pulau Palawan). Further, we observed more occurrences of "trouble and repair" as compared to knowledge generative task type. We attribute this to the presence of the real world platform - the rich physical affordances that somewhat "complicates" seemingly easy procedural and applicational tasks. The interaction with the real environment presented some *unforeseen variables*. Application skills such as mapping, measuring of gradient, determining directions and bearings become complex to the participants in an outdoor context endowed with rich physical affordances. Concepts and skills they have learnt and "practised" within the four walls of the classroom, were no longer as clear-cut for transfer into the current context. The problem-solving process necessitated collective review of ideas, negotiation and finding consensus. The rich semiotic resources present in an outdoor learning context created new challenges and opportunities of looking at familiar tasks and formulas. The situated interpretative nature of the mobile learning context (Pachler et al., 2010) cannot be

underestimated for learners leverage on emerging resources specific to the learning context, to interpret and to interact with the environment in the meaning-making process.

Contingency action versus conditioning in interacting with artifactual resources

In the following episode, we address how prior learning experiences affect the way learners employ the semiotic resources in an outdoor mobile learning context. Here, we foreground Knoblauch's (2009) notion of "habitualised, routinized and institutionalized" (p.13) meanings on action where he sees *conditioning* as possessing considerable impact on current action and meaning-making.

Episode 2 is about Group 1's interaction and discourse at learning station A where they were tasked to describe the dimension of the tunnel. Learners were unanimously certain that the dimension of the tunnel resided in the artifactual resources such as exhibits and displays delivering information about the history and structure of the tunnels. Group 1 participants approached exhibits and displays (see Lines 7 - 12) chiefly to look for answers. In a bid to save time and human resources, group eventually spilt up to look for answers on the displays and exhibits (Lines 5, 9 & 13).

Table 3	: Episode 2	2 – Group 1 enters tunnel B and their imm	nediate preoccupation is to look for answers to the					
	first task	question, which is to describe the dimension	on of the tunnel					
	1							
Line	Student	Verbal	Nonverbal					

Line	Student	Verbal	Nonverbal
1	А	Describe the dimension of the tunnel.	Team gathers for a very short while at the end of the
2	D	What dimension? 3D dimension or the	stairways and takes a quick glance around the tunnel. A reminds team of the task question.
3	В	4 dimension	
4	С	Dimension dimension. Why do you want us to find dimension? What dimension?	
5	В	Eh It might be written on the wall.	Team appears certain that the dimension can be found on the exhibits as they hurry from display to display and move briskly from one exhibit to another in the tunnel (perhaps too accustomed to conventional field trips tasks where answers are derived from displays or artifacts).
6	D	Look at the question first.	A, B & C forge ahead and scan through the exhibits very quickly for clues on dimension. D lags behind and calls out to the rest to review the question. She finally gestures A to the bench. They re-read the question. C & D join them.
7	В	Calvin, you search here. I go and search there	B proposes a spilt to look for answers. He suggests that the team be spilt into two as they have two task questions to complete at the tunnel – one was the dimension and the other; the purpose of the tunnel.
8	С	Search what? Search what? [louder]	C is confused by the division of labour.
9	В	Search, search for the dimension	B replies C as he is walking off (B & C are supposed to look for dimension).
10	А	Yea whatwhatwhat dimension	A gets a little agitated and seeks affirmation on task
11	D	Ok. You find what is the dimension and the purpose	and role assignments.
12	A	No. No. Bob find dimension, Calvin finds the necessary and we go and find purpose.	A looks impatient and corrects D.
13	В	But, purpose is over there!	B notices A & D are heading the "wrong" direction
14	А	Oksorry. Ok. So what is the purpose?	and reminds them that they are supposed to look for purpose.
15	D	No, we are finding dimension	_ F F
16	A	We all go this side	Team spilt up.

Group 1 was unable to allow the environment to speak to them amid the rich affordances of the physical environment in mobile learning. Neither were they able to comprehend the requirements of the task question correctly. The engagement and interaction with the artifactual resources (exhibits and displays) became

brief, superficial and conservative. Here, artifactual resources in the tunnel became a restraint rather than a resource because learners had approached task questions with past experiences of outdoor learning trips where they were accustomed to looking for answers in the artifacts. Prior experiences conditioned and reproduced recurring learning behaviour. Their strongly entrenched pre-conceived notion of conventional field trips not only impacts the way they interact with the real world environment to construct knowledge and meaning, but also inadvertently shapes their participation framework. We attribute such a phenomenon to what Knobluach (as mentioned in Kissman 2009, p. 13) conceives of as "fixed patterns that also shape action" when meanings become "habitualised, routinized and institutionalized socially".

Likewise, Group 2 showed initial confusion and uncertainty about describing the dimension of the tunnel. This was especially so when they saw many students reading the exhibits for answers. However, they restored their discussion track after briefly browsing the exhibits (see Episode 3, Lines 1 to 3, verbal utterances and nonverbal observations). They moved away from the exhibits, and came together to discuss, making reference to spatial resource in their description of the tunnel. Here, the participants were not entirely constrained by known protocols on field trips; rather, they were able to interact with the current environment and ride on the affordances of the semiotic resources resided in the specific situation to re-negotiate shared meanings. Akin to what Lim and Barton (2005) advocate that, 'the process of learning is informed by the sense of place', Group 2 developed a sense of situational intent and was able to engage with the artifactual resources to make valid interpretation and inferences.

Line	Student	Verbal	Nonverbal			
1 E		What is, what do you mean by dimension?	Student E & Y descend the stairways leading to the tunnel. Student G is just right behind them, reading the task question aloud. Student E voices her query on "dimension", she is not sure what is required of them.			
2	G	That means the tunnel, how big is this, is it cramp or what?	The three students are now at the entrance to the tunnel. They look around. Student E & Y, upon seeing many students reading the exhibits, approaches one of the displays briefly. Student Y moves to look around the tunnel, trying to do some the spatial reasoning.			
3	Е	Is it cramped?	Student E moves away from the exhibits to look around the tunnel.			
4	Y	What's the dimension of the tunnel	Student G moves to the bench; looks into the iPad.			
5	G	Dimensions? Ermdimensions. Ehwhy why where	Student Y & E stand beside him but continues to look around the tunnel.			
6	Е	There's quite narrow.	The three students come together to discuss their			
7	G	6.	viewpoints, making references to the spatial resources to make some conclusions about the dimensions of the			
8	Е	10.	tunnel. They conclude that it is about 6 feet wide,			
9	Y	6. Gavin can only fit like that.	using student G's size as a gauge.			

Table 4: Episode 3 – Group 2 enters tunnel B to review the task question and to visit the tunnel

Conclusions and implications

This research study reports our initial efforts to investigate how learners leverage the use of semiotic resources in the physical, social and material world to construct and converge at shared meanings. It enables us to make sense of how and why learners leverage the available resources, and how they repair and restore a projected sequence to accomplish collective goals.

Our two key findings reported here afford us some insights into the challenges and implications in designing and implementing mobile learning activities. First, in an outdoor learning context where contextual configurations cannot remain constant, learners assemble and reassemble the physical, social and material resources in 'trouble and repair' to negotiate and to re-converge at new meanings and shared understanding. Designing mobile learning could consider how we can help learners response to changing contextual resources in an outdoor learning environment to advance their learning collectively. Instructional scaffolds and technological supports could empower learners in their interaction with and the interpretation of the learning environment in the meaning-making process. Technological support, while provisions could be made for

learners to deploy other technological tools where they deem more relevant at the point of contextual reference. Second, the richness of the semiotic resources present in an outdoor environment has a bearing on task-types (aim and structuredness of the task), and consequentially, shapes how learners leverage use of available resources in the physical and material world in the meaning-making process. Task design in mobile learning could see a combination of structure and unstructured learning space, where the latter might make provisions for the environment to speak to the learners; i.e. learners be given that platform to see relationships. Further, prior experiences and past conditioning could affect learners' use of semiotic resources. This is evident in our second finding that conditioning has a profound impact on current action and meaning making. Learning activities could possibly create space for learners to develop a sense of situational intent and the capacity to ride on emerging semiotic resources.

We acknowledge that there could be limitations to our findings and conclusions as mobile learning design and practices vary from context to context and across different subject disciplines. Further, the communities of practice and the socio-cultural conditions of learning can neither be predetermined nor prescribed, as it is nurtured and refined overtime. Nevertheless, our initial efforts to understand how learners leverage use of multiple semiotic resources for collaborative meaning making, will provide some insights into the richness of an outdoor learning context, in particular, the opportunities and challenges in exploring the material conditions for learning.

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Modeling Performance in Asynchronous CSCL: An Exploration of Social Ability, Collective Efficacy and Social Interaction

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Abstract: Previous studies have invested effort in understanding the factors affecting student learning from isolated perspectives. Based on social cognitive theory, this study proposes two dynamic CSCL models of learning using understudied factors – system functionality, social ability, collective efficacy and social interaction – to examine mediation and causal relationships among these constructs and their influence on learning. The models are tested using data collected from a large US university. Specifically, while the predictive constructs are operationalized through the survey instruments, outcome measures are modeled using electronic trace data and actual evaluation information. Data is analyzed via the Partial Least Squares method. Results demonstrate close relatedness among the constructs and a different influencing mechanism on learning for each. The addition of social interaction as a factor to the learning model increases predictability of student learning as compared to models without this factor. The paper concludes with discussion of the implications of this study.

Keywords: CSCL, social ability, collective efficacy, social interaction, PLS

Introduction

Researchers have taken considerable effort to understand the factors affecting student achievement in computer supported collaborative learning (CSCL). Previous studies, however, have investigated these factors from more or less isolated perspectives. Kirschner and Erkens (2013) classified these perspectives into three categories: pedagogy, technology, and human factors. From pedagogical point of view, Shaw (2013) studied group sizes and the impact on programming language learning. Jackson et al. (2013) explored the effect of interactive tabletops on elementary students' mathematical achievement. From a human factors perspective, Joksimovic et al. (2014) reported how individual differences (e.g., working memory) influenced perceived cognitive presence in communities of inquiry. These approaches, despite their contributions to our understanding of CSCL to date, have overlooked emergent dynamics created by multiple factors across categories. For example, one might question how groups perceive pedagogies and technologies to experience of agency, social interaction, and learning. Given that CSCL builds on person-environmental reciprocity in socio-technical systems (c.f., Bandura, 1986), it is important to examine internal forces and synergies that result from interactions among multiple factors, including pedagogy, technology, and human factors.

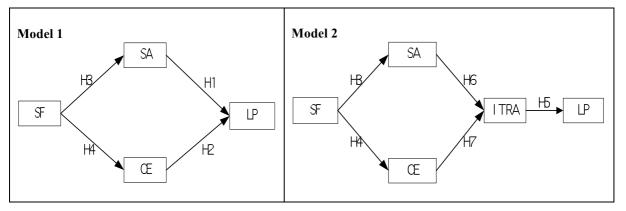
The current study, therefore, proposes and validates a model of learning that sheds light on dynamics across several factors that are particularly understudied in CSCL. Specifically, with inspiration from social cognitive theory, we examine how cognitive factors—social ability and collective efficacy—influence student learning while mediating the impact of technological environments—system functionality—on learning outcomes. Social ability, the perceived individual capacity to perform well within social-technical systems, is a fitness measure among task, technology and people (Yang et al., 2006). It is a factor not captured by previous approaches isolating pedagogy, technology and human factors. Few studies have investigated how social ability correlates with other factors to influence CSCL. Similarly, Bandura (2000) suggested that collective efficacy, the group's shared belief that it can execute a task successfully, has positive impact on various aspects of group learning and performance. There is, however, little research examining the role of collective efficacy in CSCL. Introducing social ability and collective efficacy and constructing a dynamic model of learning with them has the potential to improve our understanding of how learning takes place in CSCL.

We further build an alternative model to examine how these factors (system functionality, social ability, and collective efficacy) are ultimately embodied as social interaction behavior influencing student learning outcomes. This model specifies social cognitive theory's triadic reciprocity of environment-cognition-behavior in CSCL. For example, system functionality is measured as task-specific support. Social ability is measured as the fit between person, task, and tools in CSCL. The second model aims to illustrate the influencing process of these factors on social behavior and learning, and outperforms the first model in predicting and explaining learning.

Theoretical background and research models

Social cognitive theory (Bandura, 1986) builds on reciprocal determinism, which indicates that environments and persons influence and shape each other. Environmental factors refer to social and physical characteristics—system functionality in our study. Human factors represent 1) psychological characteristics such as knowledge, beliefs, and emotion and 2) their involvement in cognitive and social events. With inspiration from social cognitive theory, we consecutively built two CSCL models of learning to explore and elaborate CSCL dynamics. System functionality (SF), social ability (SA), collective efficacy (CE) and social interaction (ITRA) are exogenous or/and mediation variables. Learning performance (LP) is an endogenous variable. Table 1 presents each model.

Table 1: Research models



Model 1

Previous CSCL studies rarely considered psychological characteristics among human factors (Joksimovic et al., 2014). Our first model highlights how environmental impact is mediated by beliefs related to ability at both individual and group levels to influence student learning. First, the construct of social ability is a synthetic representation of individuals' beliefs about their capacity to learn within a surrounding environments' social affordances. Yang et al. (2006) suggested a social ability measure for online group learning contexts comprised of five factors: social navigation, peer social presence, instructor social presence, written communication, and comfort in sharing personal information. Social navigation indicates that students can perform well due to the visibility of actions of other students in the online system (c.f., Dourish, 1999). Social presence reflects student confidence in social interaction. Clear communication through writing is an especially crucial factor for student success in asynchronous online learning. Finally, in a less private space, learners may feel uncomfortable in sharing some types of information, which in turn affects the interaction between group members. Instead of being a single dimension measure, social ability captures intricate effects of the interaction between person, task and tool. Social ability is previously shown to be a significant predictor of online learning satisfaction and participation pattern change; students with higher social ability move from peripheral to central roles in an online CSCL courses (Tsai et al, 2008). We therefore assume a positive relationship between social ability and learning outcome:

H1: Social ability has a significant positive effect on student learning.

Social cognitive theory posits efficacy, belief in one's own ability to complete tasks, as an important factor that guides human behavior. Research on efficacy has been essentially confined to self-efficacy exercised individually. However, this is not the only way in which a person can bring an impact on learning. Bandura (2000) suggested extending the notion of self-efficacy to collective efficacy. It is a notion that exits in the mind of group members, or group's shared beliefs in its conjoined capabilities to execute the actions required to achieve common goals (Bandura, 2000). Perceived collective efficacy is particularly relevant when the goal achievement requires a massive amount of interdependent efforts, which is usually the case in CSCL. Lent, Schmidt and Schmidt (2006) conducted an experiment to show that collective efficacy is even a stronger predictor of team performance than self-efficacy. Hence, collective efficacy is held to be an important determinant of student learning in CSCL:

H2: Collective efficacy has a significant positive effect on student learning.

The quality and usefulness of the technological systems is a fundamental determinant of effective online learning (Schwier, 2002). Therefore, system functionality is considered as a base factor influencing learning. System functionality in our case is the perceived ability of the environment to provide task-specific support, problem solving, and collaboration. Without quality system provisions (e.g., communication channels), students may feel isolated and depowered to accomplish the scheduled tasks. In Schwier (2002)'s study, therefore, system functionality was crucial to building online learning communities. As a foundational infrastructure for students to be social, we assume system functionality will affect students' perceived social ability:

H3: System functionality significantly influences social ability

Similarly, the technological environment serves as a determinant of collective efficacy. Social cognitive theory posits that past success, vicarious experience, verbal persuasion, and physiological cues (c.f., Bandura, 1986). We assume that system functionality can promote collective efficacy by providing effective communication channels, which make visible other students' success traces, support group regulation, and enable peer encouragements (c.f., Kirschner & Erkens 2013):

H4: System functionality has a significant positive effect collective efficacy.

Model 2

Social cognitive theory also emphasizes that the person behavior (i.e., involvement in cognitive and social events) embodies psychological characteristics to influence the social environment. In the same vein, our second model adds social interaction to the first model to mediate paths between belief in ability and student learning. Social interaction in the current study is modeled as individual contribution to in-group dialogues encompassing peer interaction and student-to-instructor interaction. First, social interaction is important process mechanisms in CSCL (Stahl, 2006). As a key factor of success in CSCL, we assume that social interaction not only promotes cognitive processes in collaboration (e.g., reasoning, critical thinking, and reflection) but also develop positive affective relationships, which directly influence learning (c.f., Yang et al., 2006):

H5: Social interaction has a significant positive influence on student learning.

As a behavioral factor, social interaction also mediates social ability and collective efficacy to influence learning. As a positive learning climate encourages exchanges of opinions and information (Wu, Tennyson & Hsia, 2010), we assume strong ability beliefs reflecting positive social affordances will contribute to efforts invested by students to collaborate and interact during CSCL:

H6: Social ability has a significant positive influence on interaction.

H7: Collective efficacy has a significant positive influence on interaction.

This second model is expected to outperform the first model in explaining student learning variances in the CSCL context.

Methods

Research context

The data reported in this paper represent a subset of data gathered in a larger study conducted in the context of an online graduate student course on Computer Support for Collaborative Learning, offered in a large midwestern US university. Twenty-four students were divided into eight small groups at the end of the first week of an eight week summer session and completed all course activities in the context of that small group for the remaining seven weeks of the course. The collaborative environment that supported the CSCL course was Sakai. The CANS (http://www.cansaware.org) system was also applied to provide activity awareness information. When a student logged into Sakai and posted a message or read a message, CANS logged the information automatically. Specifically, the data we analyzed from Week 5 and Week 6, where the group activity is to design a two day online learning module consisting of three parts: scenario, script and assessment. Survey data were collected before Week 5 and the log data from CANS were gathered after week 6 when the module was completed.

Measures

All instruments were adapted from existing literature to increase validity. Social ability is measured via the social ability survey composed of 5 constructs developed by Yang et al. (2006). Collective efficacy was operationalized through a 4-item survey constructed by Hardin et al (2006) for virtual teams. System functionality was informed by Sonnenwald's (2005) information horizons concept about how a person perceives

the usefulness of an environment that was adapted to Sakai including 5 items. The system functionality was presented to students with a five-point Likert scale, and the other two are with a seven-point Likert scale.

Most previous studies applied self-reported questionnaires to reflect student learning performance construct (e.g. Yang et al., 2006; Wu, Tennyson & Hsia, 2010). However, a common bias exists if independent variables (social ability, collective efficacy, system functionality) and dependent variables (social interaction and student learning performance) are reported by the same individuals. To avoid such a bias, this study applied actual assignment and evaluation data to generate measures for student learning. The purpose of the module analyzed was for group members to develop an online module that can be implemented in a real-life environment. Two raters proceeded to evaluate the three work products – scenario, script, and assessment – and generate a group grade based on the rubric. Each individual student was then asked to rate and nominate their group members and the whole class. The frequency of rating from other group members or other students is considered a reflection of the individual grade. Therefore, student learning performance is represented by two indicators – group and individual grade.

In this study, social interaction is approached from a network theory perspective. Individuals must socialize to form a group which shares goals and values. The way individuals are situated in social networks, i.e., the structure of groups, significantly affects the creation of social capital (Cho et al., 2007). Students occupying structurally advantageous positions have a better opportunity to influence others, and thus play a more important role in the social space. In network analysis, degree centrality has been used to examine the advantageous positions of individuals. Persons with high degree centrality are assumed to be more active and influential due to the many ties and connections they have with others in the social structure (Freeman, 1979). From the perspective of graph theory, degree centrality is a quantification of the relative importance of a node within the graph. It indicates the number of links the student has with other students in the course.

Partial least squares (PLS) modeling

PLS method is a multivariate statistical modeling technique used to test the relationships between a set of independent variables and dependent variables. It is considered to be the second generation of multivariate analysis (Fornell & Larcker, 1982), integrating multiple regression, path analysis, principle component analysis, and multiple discriminant analysis. As a component-based structural equation modeling technique, PLS is particularly suitable for predicative applications, while the linear structure relationships (LISREL) model is more oriented towards theory testing and development.

Normality assumption is not required for PLS, and the technique shows utility even with small sample sizes (Chin Marcolin & Newsted, 1996). By conducting a Monte Carlo simulation study on PLS with small samples, Chin, et al. (1996) found that the PLS approach can offer information about the appropriateness of indicators for sample sizes as low as 20 and even under the condition that the number of variables surpasses the number of observations. Fornell and Bookstein (1982) states that "PLS involves no assumptions about the population or scale of measurement and consequently works without distributional assumptions and with nominal, ordinal, and interval scaled variables" (p. 443). Considering the relatively small sample size and the explanatory nature of the study, the PLS method is preferred for model testing in this study.

Results

Measure models

This study applied two-step analysis. The measurement model was first estimated and re-specified and then the structural model. Tables 2 and 3 demonstrate the results for the measurement models. In terms of individual item reliability, Chin (1998) indicated that items should load highly (greater than 0.7) on their intended constructs. Loadings with 0.5 or 0.6 are still acceptable on the condition that there are additional indicators in the construct for comparison analysis (Chin, 1998). As a result, items such as Item 4 in system functionality, Item 2, 3, 7 in social ability, and Item 1 in collective efficacy were removed according to the criteria. Then all the factor loadings of the measurements (Table 2) met the suggested condition.

To evaluate the internal consistency and construct reliability, composite reliability was calculated. As suggested by Nunnally (1978), composite reliability should be greater than 0.7, which most of constructs in this study satisfied (Table 2). The learning performance construct was close to 0.7 and is generally considered acceptable in social science. Regarding convergent validity, it was suggested that the average variance extracted (AVE) for each factor should be larger than 0.5. Table 2 shows the values of AVEs meet the recommendation. Discriminant validity is valid if the squared root of AVE is greater than the correlations between latent variables (Fornell & Larcker, 1982). Table 3 indicates that all the scales meet the suggested requirements to indicate an adequate level measurement validity.

Construct	Composite reliability	AVE	Item	Loading
System Functionality	0.88	0.73	SF1	0.93
			SF2	0.78
			SF3	0.82
			SF5	0.88
Social Ability	0.92	0.57	SA5	0.80
			SA6	0.79
			SA9	0.74
			SA14	0.69
			SA15	0.90
			SA16	0.64
			SA18	0.88
			SA19	0.70
			SA21	0.79
			SA28	0.58
Collective Efficacy	0.73	0.64	CE2	0.89
			CE3	0.78
			CE4	0.73
Interaction	1.00	1.00	INTR	1.00
Learning Performance	0.66	0.55	LP1	0.99
			LP2	0.79

Table 2: Item loadings, construct reliability and convergent validity

AVE = Average Variance Extracted

Table 3: Discriminant validity.

Construct	SF	SA	CE	INTR	LP
System Functionality	0.85				
Social Ability	0.47	0.76			
Collective Efficacy	0.28	0.22	0.80		
Interaction	0.53	0.37	0.31	1.00	
Learning Performance	0.69	0.28	0.29	0.58	0.74

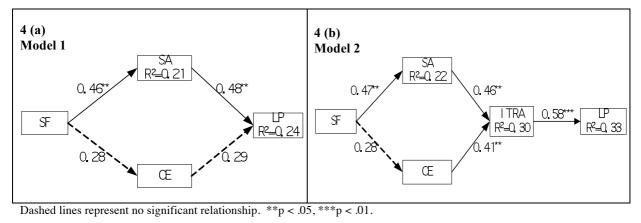
Diagonal elements (bold) are the square root of the AVE of each construct.

Structural models: Direct effects

The explained variance (R^2) in the endogenous variables and the significance of the coefficients are the indicators of model performance (Chin, 1998). For Model 1, as shown in Table 4 (a), social ability had a positive relation to learning performance (0.48, p < .05) and therefore supported H1. However, H2 was not supported since collective efficacy had no significant relationship with student learning. Again, system functionality had a significantly association with social ability but not with collective efficacy. The explained R^2 for student learning in Model 1 was 0.24.

In terms of Model 2, H3 and H4 obtained the same results as in Model 1 showing that system functionality significantly influenced social ability but not collective efficacy. However, both social ability (0.46, p<.05) and collective efficacy (0.41, p<.05) had significant associations with social interaction supporting H5 and H6. Social ability was a more influential factor on social interaction than collective efficacy. Again, social interaction influenced learning performance significantly (0.58, p<.01). The social interaction factor was more influential than social ability on learning performance when we compared path coefficients across Model 1 and 2. Moreover, the R² in Model 2 was 0.33, which was higher than 0.24 in Model 1. Therefore, Model 2 has better predicting performance of student learning than Model 1.

Table 4: Model performance



Structural models: Mediation analysis

We further examined indirect, mediation effects in Model 2. Baron and Kenny (1986) suggested three steps to examine mediation effects: a) the independent variable must be significantly correlated with the mediator; b) the independent variable must be significantly correlated with the dependent variable; c) both the independent variable and mediator should be employed to predict the dependent variable. If both independent value and mediator significantly explain the dependent variable, then this mediator partially mediate the effect of the independent variable on the dependent variable. If only the mediator is significant, then the mediator fully mediated the independent variable effect on dependent variable. Table 5 presents the experiment results.

IV	М	DV	IV -> DV	IV -> M	$IV + M \rightarrow DV$		Mediating Effect
					IV	М	
SF	SA	LP	0.56**	0.64***	0.26	0.49**	Fully Mediated
SA	INTR	LP	0.46**	0.76***	0.32	0.29	Not Supported
CE	INTR	LP	0.32	0.32	0.15	0.54**	Not Supported
*p < .05, **p < .01, ***p < .001							

As shown in Table 5, the direct link between system functionality and social ability was significant and hence satisfied the first condition. Then the link between system functionality and learning performance was significant meeting the second condition. The direct link between system functionality and learning performance becomes insignificant when controlling for the link between social ability and learning performance. Therefore, social ability fully mediated the relationship between system functionality and student learning performance. Using the same logic, social interaction did not mediate the relationship between social ability and learning performance performance. Again social interaction did not mediate the relationship between collective efficacy and learning performance.

Conclusions and implications

Informed by social cognitive theory, this study built two different CSCL models of learning especially contributing to the understanding of the role of social ability, collective efficacy and social interaction in CSCL. The results revealed that system functionality significantly influenced students' social ability, which again fully mediated the system functionality effect on student learning. Social ability also showed a significant effect on student learning. However, system functionality did not affect collective efficacy significantly, and collective efficacy had no significant influence on student learning. Both social ability and collective efficacy had significant effects on social interaction, but social ability was a more influential predictor for social interaction. Finally, social interaction significantly impacted student learning performance and served as a stronger predictor than social ability in explaining student learning. Social interaction, however, did not mediate the influence of social ability and collective efficacy on learning.

To sum up, the addition of the social interaction factor (Model 2) increased the predictive power of our model of student learning over the model without it (Model 1). Social interaction alone had the strongest impact

on student learning, which is well supported by CSCL literature. In addition, when students were supported by well functioning environments, which also impacted on social ability, students were more likely to interact with each other and tended to have higher learning performance. Technology designs focused on supporting learning activities as well as fluid social interaction, therefore, appear to enhance learning overall.

However, linkage between beliefs about ability and learning was not evident. Though beliefs about ability had significant direct effects on social interaction, results failed to prove beliefs about ability can reach far to impact student learning outcomes. The results may be explained by two reasons. First of all, CSCL studies frequently report free-rider effects when some students do not contribute to group works. It might be the case when students believe their group members outperform themselves, they may not be willing to exert their best efforts (Piezon, 2005); therefore, collective efficacy may not guarantee successful student learning outcomes. Also, it should be noted this study utilized degree centrality as a social interaction measure. Though degree centrality impacts learning significantly, different attributes of interaction might be considered to mediate ability beliefs and impact on student learning. For example, a student in a central role may or may not be contributing to the learning of others. In this case, how one student disseminates important information and how other members rely on this student (i.e., betweenness centrality) may be a critical indicator of quality interaction. Future research may examine how to build a social interaction measure that integrates both the quantitative and qualitative aspects of information and incorporates it into the proposed model of learning and test its effect.

The findings of this study are important in that previous studies found the direct effects of social ability, collective efficacy, and system functionality on student learning mostly not controlling for or explaining other factors. But it seems that dynamics among these factors are far more complex than reported. The reported study enriches literature on student learning in CSCL by providing new insights into the influencing mechanisms of these factors. Methodologically, previous studies have only used self-reported data to measure all the constructs used in the model. However, self-reported participation or evaluation instrument may not address the student performance appropriately and can be different from the actual case (Tsai et al, 2008). Moreover, the potential of common method bias exists if both independent and dependent variables are self-reported by the same persons. Unlike those works, the present study applied actual evaluation of the student works as the learning performance indicator, in alignment with Goggins' (2009, 2013a, 2013b, in press) and Xing's (2014a, 2014b, 2014c, 2014d, 2015a, 2015b) data analytics approaches to the examination of trace data, "Group Informatics". In addition, this study took advantage of the advancement of information systems by modeling student social interaction using electronic trace data informed by network theory. Our study demonstrates a potential approach to measure the constructs in CSCL studies and possibly with more validity and objectivity.

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Grappling with the Not-Yet-Known

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Abstract: The importance of shared artifacts as means for learning has been widely acknowledged in the learning sciences as well as within the field of CSCL. However, there is no consensus on the actual roles these artifacts are playing in processes of (collaborative) knowledge creation. In this paper we argue that the prevailing theoretical accounts block sight for important epistemic processes and also hinder a deeper understanding of the material qualities of use as they focus on the explication of what is known rather than on what is not known yet. Drawing on an ethnographic study in a design studio course on industrial design, we depict the use of design artifacts in a set of epistemic patterns. Based on the conclusion that these artifacts can be understood as objects used to come to terms with the unknown, we discuss potential implications for CSCL systems aimed to foster collaborative knowledge creation.

Keywords: knowledge building, knowledge artifact, case study, tool design

Introduction

The development of tools in support of collaborative knowledge creation cannot be decoupled from the striving for a better understanding and theorization of the ways people actually work together to produce new knowledge (e.g. Farooq, Carroll & Ganoe, 2005) as well as the role of the artifacts used in these processes (e.g. Eckert & Boujut, 2003). Many recent computer-supported collaborative learning scenarios engage learners in working on ill-structured and open-ended problems, be it in the fields of research, engineering, or design. Respective scenarios have challenged pre-established conceptions of the artifact, as a resource of information or as a means for communication (cf. Envedy & Hoadley, 2006) and raised the question of the epistemic role artifacts are playing in processes of inquiry, design, and knowledge creation. Stahl, Ludvigsen, Law & Cress (2014) most recently positioned artifacts as central to CSCL as, among others, collaborative learning essentially might be oriented towards and result in the creation of knowledge artifacts. However, despite the recurrent call for a deeper understanding of the function of artifacts for collaborative knowledge creation, there is an inclination to conceive respective artifacts, be them a theory, a model, a research paper, or a designed object, as an externalization or embodiment of what is known (cf. Bereiter, 2002; Stahl, 2006; Kimmerle et al., 2010). Even if it is emphasized that the respective artifacts "are in the process of being developed" (Paavola & Hakkarainen, 2009, p. 84) and therefore tentative, incomplete, or ambiguous, they are primarily understood as means to explicate, reify, and convey ideas about what is or should be. However, these conceptions inevitably foreground issues that are already expressible, or even agreeable, including the problems to be solved and the questions to be answered. In doing so these conceptions bracket out all those instances in which artifacts are created and used to actually figure out what is not known yet, where people engage in situations that are essentially uncertain and open-ended, and where artifacts cause puzzlement and surprise.

Against this background we argue in this paper that to deepen the understanding of the role of artifacts in processes of knowledge creation, we have to overcome representational notion of artifacts but to reconsider them as artifacts of inquiry, essentially aimed to come to terms with what is not known yet. Drawing on the notion of epistemic artifacts as suggested by Knorr-Cetina (2001) and Rheinberger (1997, 2006) as well as related work in fields of scientific modeling (Knuuttila, 2005) and design research (Gedenryd, 1998) we will sketch a conception of epistemic artifacts as objects in and through which participants circumscribe, raise awareness, and bring to the fore the limitations and lack of knowledge they deem of relevance for the inquiry processes they are engaged in. To illustrate the fact that representational conceptions of knowledge creation, we depict and discuss a set of epistemic patterns we found in an ethnographic study of a design studio course on industrial design. Based on the theoretical considerations and empirical findings, we finally discuss potential implications for CSCL systems aimed to foster knowledge creation.

The contributions of this paper to the field of CSCL are threefold. First, on the theoretical level the paper delineates some of the limitations inherent to representational notions of knowledge artifacts. Second, in

providing examples on the use of artifacts in an educational setting it raises awareness for the commonly intricate nature of an artifact's use and its material entanglement. Third, the paper challenges current approaches to the design of CSCL systems that downplay or bypass the material nature of many artifacts and respective knowledge practices.

Knowledge artifacts: Two incompatible conceptions

In the following we briefly review the theoretical accounts of knowledge artifacts that figure prominently in the field of CSCL and then contrast these with a non-representational account of artifacts. Our focus is on those theories that explicitly deal with the notion of knowledge artifacts. Even though these accounts do so under somewhat different labels, they all posit that a particular type of artifact is at the center of collaborative knowledge creation.

Knowledge artifacts in theories of CSCL

In his theory on knowledge building Bereiter (2002) develops the notion of conceptual artifacts, "which are human constructions like other artifacts, except they are immaterial and, instead of serving purposes such as cutting, lifting, and inscribing, they serve purposes such as explaining and predicting" (p. 58). These conceptual artifacts, which include for example "ideas, facts, theories, algorithms, designs, problem formulations and problem solutions" (p. 64), are conceived as immaterial yet objectively existing entities. While Bereiter argues that it is the "thing-like" nature of these artifacts, which "makes it possible to treat them as objects of study and discussion" (2002, p. 66), he makes a clear distinction between conceptual artifact as such and its material representation, e.g. in the form of text or graph. This distinction becomes most evident when he states that: "When we argue about a theory or design we are not arguing about a piece of paper or about the particular words or lines on the piece of paper. We are arguing about the abstract knowledge object of which those words or lines are but one possible representation" (ibid, p. 64). This conception however implies that a conceptual artifact is essentially independent of both the conditions of its own production as well as the material carriers that embody or represent it. Thus the material artifacts (physical or digital) are seen as partial representations of some abstract conceptual artifacts the students or knowledge workers are trying to create or improve.

A quite similar figure can be found in the accounts provided by Stahl (2006) as well as Kimmerle et al. (2010). Stahl (2006) also emphasizes the role of artifacts and argues that "the knowledge-building process can be conceptualized as the construction of knowledge artifacts, involving physical and symbolic artifacts as starting point, as medium, and as product" (p. 239). Stahl avoids to make a strict distinction between conceptual artifacts and their material embodiments as suggested by Bereiter. In fact, content and form appear to be somehow intermingled in Stahl's conception of knowledge artifacts when he introduces "a verbal problem clarification, a textual solution proposal, or more developed theoretical inscription" (p. 3) as examples. However, when turning to the role of artifacts he conceives them as "embodiments of meanings that have been embedded by the artifact designers or creators; new users of the artifact must bring those meanings back to life" (p. 294). Hence, also in this account there is supposed to be a meaning embodied or represented in the knowledge artifact that is independent of its material carrier.

Kimmerle et al. (2010) in their co-evolution model of cognitive and social systems more recently also emphasized the role of what they labeled as epistemic artifacts. In focusing on social software such as wikis and social-tagging system they stipulate that "collective knowledge manifests itself in shared digital artifacts" (p. 10). They conceptualize the work around these epistemic artifacts as continuous processes in which individuals on the one hand externalize cognitive concepts and articulate their knowledge while on the other hand they internalize and draw on the information entailed in the epistemic artifact. Both internalization and externalization require a translation in which people have "to couch their cognitive concepts in words" and "to consider the information which is already available in an artifact in order to integrate their own thoughts adequately" (Kimmerle et al. 2010, p. 11). Again the material artifacts such as wiki pages and tags are basically understood as more or less arbitrary carriers of some information articulated and retrieved by its users.

In their model of trialogical learning Paavola and Hakkarainen (2009), finally, explicitly emphasized the concrete and material nature of the shared objects knowledge creation processes are targeted towards. They highlight the evolving nature of what they call trialogical objects, which comprise of such diverse things as "knowledge artefacts, practices, ideas, models, representations, etc." (p. 84), and the iterative processes through which these objects are developed and modified. However, the relation between knowledge artifacts, practices and externalized ideas and representations remains opaque in this account. If, for example, a joint research article qualifies as a shared object of knowledge creation (ibid. p. 86) we have to concede either that the research article is a self-contained entity or that it refers to and in this sense provides a representation of some other object, be it an empirical phenomenon or a conceptual artifact. Even though it is contrary to Paavola's and

Hakkarainen's stated intentions, their conception of trialogical objects easily boils down to a representational account of knowledge artifacts as something "that embodies the understanding, meaning, or knowledge that has been constructed" (Damşa, 2014, p. 254).

In summary, despite the different schools of thought the above concepts of knowledge artifacts are based on, they all imply that the material objects that are produced and used in the processes of knowledge creation are essentially representational devices, be it that they represent some conceptual artifact, some meaning, understanding or knowledge. In this sense, all of them are inherently focused on what is already known rather than on what is not known yet. The underlying claim, that in our understanding renders these accounts problematic, is that there is a kind of knowledge that can be effectively separated from the conditions of its own production and its material embodiments.

Knowledge artifacts as embodiments of the not-yet-known

Aiming to sketch an alternative perspective on the role of knowledge artifacts in processes of knowledge creation we draw on the conceptions of epistemic objects developed by Rheinberger (1997, 2006) and Knorr-Cetina (2001).

Based on the assumption that scientific research essentially takes place at the borders of the known and the unknown, Rheinberger (1997, 2006) introduced the concept of epistemic objects, which embody what one does not yet know. In Rheinberger's conception these epistemic objects, which he alternatively labels as the objects of the research or epistemic things, are a part of historically evolving experimental systems the researchers are engaging in. These experimental systems, in which epistemic and technical objects are intrinsically entangled, are not conceived by him as apparatuses to test ideas or provide answers but essentially as arrangements in which questions, which are not yet raised beforehand, materialize. In this sense Rheinberger's main intent is to position epistemic objects in the context of discovery rather than justification.

In building on Rheinberger's ideas, Knorr-Cetina (2001, p. 181) stresses the epistemic object's "changing, unfolding character – or its lack of 'object-ivity' and completeness of being, and its nonidentity with itself' and introduced the notion of "partial objects" as material instantiations of the unfolding epistemic object. For Knorr-Cetina these "partial objects" might take the form of "partial simulations and calculations, technical design drawings, artistic renderings, photographs, test materials, prototypes, transparencies, written or verbal reports, and more" (p. 182). However in her conception, the "partial objects" are neither a referent to nor a representation of the epistemic object but they have a "signifying force" due to their "internal articulation" (Knorr- Cetina, 2001, p. 183). The upshot of this conception is that the epistemic objects we are interested in cannot be separated from the partial objects used to imagine, simulate, represent, measure, or realize just these objects. Hence, we are inclined to conceive all those material artifacts that are produced and used in processes of knowledge creations as "partial objects" rather than as representations of some knowledge object. Following Knorr-Cetina (2001) we concede that the significance of the respective artifacts is not so much in the meaning or information inscribed into them, but in "the pointers they provide to possible further exploration" (p. 183).

Similar notions of artifacts as means to come to terms with what is not yet known have been put forward in the fields of scientific modeling and design research. For example, Knuuttila (2005) suggested to reconsider scientific models as "investigative instruments" or "productive things" which are partially independent of both the domain theory (or formal domain knowledge) and the world. As purposively created artifacts, she argues, modelling should not be treated as an isolated activity but as an integral part of more overarching practices of scientific inquiry or product development. In turn that implies that the models itself are entangled with the object of inquiry. Furthermore, she argues, models have, besides their conceptual, a material form and, therefore, are subject to the affordances and constraints of the medium used for modelling. For example, tools might enforce a certain degree of formality but also afford and constrain certain forms of expression. Finally, the creation and manipulation of models, under this conception, can itself result in new knowledge and even constitute new realities. Knuttilla points out that models are often not just used to abstractly represent a target system but to actively design or intervene in the target system.

Being concerned with the apparent gap between prescriptive accounts of the design process and actual finding of empirical studies Gedenryd (1998) came to quite similar conclusions. Rather than understanding design artifacts as intermediate outcomes or end products of the design process, he conceives them as "inquiring materials: working materials with a cognitive purpose" (p. 149). For Gedenryd design artifacts, be them sketches, prototypes, scenario or simulations, are "means for the inquiry that design is". Just as in Knuuttila's non-representational conception of models Gedenryd also stresses that the design artifacts are the very means of working on a problem, that the material they are made of severely matters and that they are closely entangled with evolving design objects themselves.

In a nutshell, what sets the latter accounts apart from the conceptions of knowledge artifacts in current theories of CSCL is (a) that the significance of these artifacts, be them questionnaires, models, sketches or prototypes, is their incompleteness and uncertainty that opens up room for surprise and future explorations, (b) the emphasis on the material qualities of these artifacts as well as (c) the constitutive entanglement with the object of inquiry.

A case study on the use of artifacts in a design studio course

To illustrate the fact that representational conceptions of knowledge artifacts are not capable to account for a variety of processes that are essential to certain forms of knowledge creation, we draw on an ethnographic study of a design studio course on industrial design. The case study was carried out in a design studio setting at the Muthesius Academy of Fine Arts and Design in spring 2013. The course we followed was part of the study program on industrial design with a specialization on Interface Design. It was conducted by a professor and a research assistant. Eleven bachelor students in their 5th semester and six master students took part in the course that lasted from April to July, spanning a period of 14 weeks. Under the overall theme "simulation/simulator" the students were asked to define and carry out individual design projects. All students enrolled in the course were included in the study. We assume, that creative design can be understood as a proper form of knowledge creation, in that it is inherently geared towards the creation original and novel artifacts, systems and services.

To develop an understanding of the creative practices enacted within this setting we drew on a collection of data sources, including (a) observations of the interactions between the students and the teaching staff during the contact hours, (b) students' narrative accounts of their working process, either voiced in students' interactions with the teaching staff or in informal interviews carried out by the research team, and (c) the material arrangements and artifacts present and utilized in the design studio. Data was recorded in the form of extensive field notes supplemented by photos and audio-recordings when feasible. A total of three observers conducted over 64 hours of site observations, taking part in more than 90 individual feedback sessions as well as the students' final presentations. In parallel, the observers wrote memos following the sessions they attended and conducted a workshop with the students and the professor aimed to elaborate on the utilization of design artifacts in the middle of the term. Each of the observers has at least two years of teaching experience in a design related domain. Informed consent was obtained from all participants including the teaching staff.

To identify common practices within the setting but also to trace variability, each of the students' projects has been treated as a distinct case in the analysis. Field and interview notes were organized into chronological case logs. Using an abductive approach, case logs and memos were used to surface patterns of interactions, which were then iteratively tested against the other cases until a stable set of patterns was found. We took patterns of interaction as a descriptive format in the attempt to shed light on the constantly unfolding network of interactions between actors and artifacts in the given setting. They describe recurring ways of how actors cope with and transform the situations they are facing. Towards this end patterns are supposed to provide middle-level abstractions in that they capture (situated) regularities in a form that is potentially verifiable and intelligible to other practitioners (Dearden & Finlay, 2006).

Patterns geared towards the advancement of ideas

The analysis of the case logs resulted in the formulation of twelve patterns, which synthesize the observations throughout the 14 weeks of students' project work. Even though not every pattern was observed in each case, the set of patterns was assumed to be characteristic for this context in that each of the patterns was instantiated in at least 50% of the projects, often repeatedly. In the following we focus on a subset of these patterns, namely those four that were most directly related to the advancement of students' project related ideas. For an overview of the entire set of patterns the reader is referred to Richter, et al. (2014).

Playing with ideas

Especially in the early stages of the design process the students and the teaching staff were recurrently engaged in highly explorative discussions on yet tentative design proposals. These discussions were not unlike brainstorming sessions in that they were associative and non-judgmental. Yet, the discussions were primarily geared to open up different perspectives rather than to produce a wealth of ideas. In sharing and taking up these "half-baked" ideas in an explorative and playful manner, the design proposals were widened and approached from multiple perspectives. In doing so the potential of the yet vague idea was collaboratively checked, not as something to be approved or rejected, but as a stimulus and springboard for more advanced ideas.

The students reported on similar kinds of explorative discussions also with fellow students, friends, relatives and other acquaintances outside the course setting. In the course context these situations occurred when

something was discussed, which was "not fleshed out, but just mulled over" as a student put it, or after an official feedback in an informal follow-up discussion. This kind of exchange about ideas was usually triggered by the students and assessed as crucial for the concept phase, both by the students as well as the instructor. In fact the instructor recurrently asked the students to share even preliminary ideas and strive for feedback.

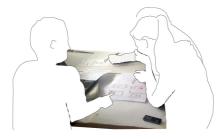


Figure 1. A student ponders with the instructor and the research assistant on an idea

In the concerned but also playful exploration of ideas, artifacts were used in two main ways. On the one hand sketches, scribbles or found objects were used to supplement the verbal presentation of the initial idea, often riddled with gestures and metaphors. On the other hand, the presented artifacts were frequently edited, commented, augmented or juxtaposed with newly created artifacts, esp. sketches, in the course of the subsequent discussions. The artifacts were used to ground the discussion but also to express ideas more directly as they evolved in the process. As the ideas to be discussed were fuzzy and preliminary, even to the students themselves, the artifacts were able to provide tentative and approximate objectifications at best.

Yet rather than being precise and definite, their value seems to be based on their capability to trigger associations and open up alternative options and perspectives. In fact highly elaborated presentations repeatedly blocked the exploration and scrutinization of the underlying ideas. The vagueness and ambiguity of artifacts hence provides an important resource to explore the design space and avoid fixation on premature solutions.

Making ideas tangible

Throughout the various stages of the design process the students have tried to make their ideas tangible, be it the form of interface sketches, moodboards, mockups, interactive prototypes or video recordings and animations. The phenomena the students were concerned with ranged from visual aesthetics, over haptic and auditory impressions, to modes of interaction and their integration of all these into coherent experience. The need to make ideas tangible especially arose when participants were dealing with concepts or ideas that entailed complex and often bodily experiences, which were hard to grasp and communicate otherwise. For example, a student working on an interactive installation realized that the physical setup, which was meant to be surprising was in fact assessed as partially frightening by the test users, prompting him to do further experiments with different setups. Or a student working on a mobile app was searching for a proper visual metaphor conveying the message "I am glad [that you contacted me] and that's why I tell you how you can come to me."



Figure 2. A student explains the envisioned interactive mechanisms with a paper mock-up

The materialization of a concept or idea usually took the form of some kind of (rapid) prototyping, in which the students learned about the experiential qualities they wanted to preserve or avoid. The tangible outcomes were then introduced to their fellow students, the instructor or some test users and tested. The actual try-out was then followed by a debriefing, in which the interlocutors tried to couch their experiences and impressions verbally. In some instances the student as well as the lecturer also used gestures and bodily postures to mimic certain experiences in the absence of tangible artifacts.

The production of tangible artifacts enabled participants to experience certain qualities of the design concept and hence added to the grounding of the design process and the interactions among the participants. This common ground, based on shared experiences, provided reference points for design decisions and furthered the development of relevant qualities of the design product and its use. Asking the students to materialize their ideas the instructor explicitly took account of the fact that many phenomena relevant to the quality of a (new) product are only insufficiently captured in abstract representations but require first-hand experience.

While the tangible objects are at best proxies for the envisioned design product, their epistemic value in this context seems to be due to the kind of first-hand experiences they provide, experiences that are more concrete and precise than any (verbal) representation would be. These experiences, which are to some extent partial, are also bound to the materials used.

Reflective prototyping

As the design concepts matured most of the students also started to develop various kinds of interactive prototypes. These prototypes ranged from simple click-through dummies, over interactive installations towards functional hard- and software-systems. While some of the prototypes where used for presentation purposes, the majority of prototypes were created to probe into the effects a certain design decision would have or whether a certain idea would be feasible at all. The issues that gave rise to the development of the prototypes were usually quite specific to the design concept, rendering existing know-how or expertise more or less futile, so that practical experimentation appeared to be a useful if not the only viable approach available. The instructor stressed the probing function of prototypes also in the discussions with the students: "When you develop prototypes] it is particularly important, that you can say that there is something that you can figure out."



Figure 3. A student presents his most recent prototype: "This is just a prototype, so that it's possible to see how it is to steer or to change speed."

Rather than providing a means to communicate or showcase a design idea, this kind of reflective prototyping was understood as an open-ended yet also focused form of inquiry in that the prototype should shed new light on issues relevant to the project. While in some cases the prototypes were used to collect feedback from others, the creation of the prototypes itself recurrently turned out be a source of insight itself, be it that the students where unsatisfied with the result, or that new issues and ideas turned up.

To retrieve timely results, prototypes were often made of malleable materials such as cardboard, styrofoam or recycled material which are at the students' disposal. Describing the components of a physical interface prototype a student explained: "I used hair gel, it was the only thing I had at hand." Nevertheless, students often spent considerable resources on the production of the prototypes and also engaged their fellow students in the production process.

The prototypes, as used here, are not just deliberate attempts to embody some abstract design concept but means to deepen the understanding of the design space. In this respect, a particular challenge for the students is to find materials and formats that provide proper answers to the questions they are concerned with.

Imaginative walkthroughs

In all stages of the design process the students and the teaching staff carried out imaginative walkthroughs in which they talked through the different steps a potential user might encounter when interacting with the envisioned design product. Aspects of the design that were covered in these walkthroughs ranged from users activities, emotions and experiences, over the coherence, adequacy and usability of the suggested interfaces to the expected outcome and impact of the entire product. A primary aim of these walkthroughs was to develop an understanding of the scenarios a potential user might find him/herself engaged in and check the implications of the respective design decision made or to be made.



Figure 4. A student and the instructor talk through an envisioned usage scenario.

Imaginative walkthroughs were either carried by the students themselves or in a collaborative manner with the teaching staff or fellow students. In the first case, the students created personas, scenarios and storyboards or engaged in some form bodystorming or self-experiment to push their concept. The insights were then presented to others later on. In the other case, the imaginative walkthrough was used as an ad hoc approach to further the mutual understanding of the intended scenarios and explore design implications.

To carry out an imaginative walkthrough, at least a minimal account of the design or the foreseen interaction sequence was used as a prompt, which eventually was expanded or altered in the course of the walkthrough. If tangible artifacts were used, they were often quite partial. For example in one of the sessions the instructor engages with a mockup of an interactive pen-device, he holds it in different positions and draws in the air while talking through an envisioned scenario. In other cases the walkthroughs were carried out without any tangible props in a purely verbal manner or based on a sequence of interface sketches.

Due to their narrative nature the imaginative walkthroughs are neither definite nor comprehensive, but itself open to interpretation. However, just because of their scrappiness and subjectivity they appear to be versatile means to develop a more empathetic understanding of a user's situation as well as to identify potential problems and bottlenecks.

Discussion

Being aware of the fact that the patterns of interaction we described above are quite sketchy and do not fully account for the overall complexity of the design efforts the students have been engaged in, these patterns however closely match the kind of inquiring engagement with design artifacts that Gedenryd (1998) has emphasized. In the patterns we also see recurrent references to the inquiring materials that he mentions, be it sketches, prototypes, scenarios or various forms of simulations. What all the four patterns have in common is that they explore into the design space aiming at new insights regarding potential constraints or potentialities. Even though the patterns address somewhat different situations, they all entail a momentum of uncertainty and lack of knowledge. In playing with ideas, the participants typically start from a vague idea or incident, which is then explored in an open-ended, associative, and non-judgmental manner. In making things tangible, they try to express ideas and experiences that are hard to couch in words and formula. In developing prototypes they explore into the feasibility of an idea as well as unforeseen (side-)effects of different design options and in the imaginative walkthroughs they simulate an assumed usage scenario trying to develop an empathic understanding of the foreseen target population and their experiences.

Trying to reduce all these efforts to the development of a clearly identifiable knowledge object in the form of a project report, presentation or the designed product itself, consequently is misleading as it implies that the insights gained throughout the design process would essentially crystalize in any of these artifacts. It ignores the epistemic value of all the sketches and prototypes that were consciously dismissed, it implies that a design artifacts has a specified meaning independent of its actual enactment in a certain usage scenario and that there is some underlying idea that could be separated from its material form. The idea that there are some artifacts in which knowledge becomes "frozen" (Damşa, 2014) discounts the inherent ""situatedness' [which] locates the design process in a world which is already crammed with people, artifacts, and practices, each with their own histories, identities, goals and plans" (Fallman, 2003, p. 227).

Implications for CSCL

While the focus of our case study has been on (collaborative) design, we believe that the findings apply to a much boarder class of knowledge-creation processes. Irrespective of whether we talk about the design of an innovative product, some basic research carried out in a laboratory or an ethnographic field study, we cannot separate the knowledge object from all the partial objects that are created and used along the way.

Apart from theoretical implications, we belief, the conception of knowledge artifacts as partial objects also has more direct implications for CSCL systems aimed to foster knowledge creation. First, in addition to tools that foster rational discourse and argumentation, there is a need for tools that allow for open explorations and surprise in that they allow collaborators to express and ponder on ideas that are inherently incomplete, uncertain and ambiguous. Second, CSCL systems have to carefully account for the material qualities of the partial objects that are used in the kind of knowledge-creation processes to be addressed. In particular it has to be acknowledged that textual accounts as well as means for visual inspection and analysis are often insufficient to come to terms with the complexity and subtlety of the phenomena and ideas often at stake in processes of research and design. Towards this end new means are needed allowing collaborators to elaborate on and share their ideas in a variety of media irrespective of whether these are physical or digital. Finally, attention needs to be drawn to the close entanglement of the technical and epistemic objects. Technical tools, including CSCL systems, are by no means neutral to the ideas we express and the phenomena we describe. This not only entails their semantic and syntactical affordances, but also their aesthetical and experiential qualities.

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Beyond and Within Classroom Walls: Designing Principled Pedagogical Tools for Student and Faculty Uptake

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Abstract: This paper tells the story of DALITE, a design-based experiment, involving a codesign project, spanning three iterations and nearly four years. DALITE was designed around the principles of peer instruction, in particular, self-explanation and intentional reflection. DALITE consists of two databases: a database of college-level physics questions and another of student-generated rationales. We report on the iterative design process that has shaped this web-based asynchronous learning environment and on its use as part of an active learning pedagogy. Using mixed methods we have tested DALITE's effectiveness to support conceptual change, examined the content of its databases, observed its use in classrooms, and conducted interviews from users – students as well as instructors. These data help to reveal the conditions of DALITE's effectiveness. We discuss our findings and provide design guidelines.

Keywords: active learning; peer instruction; design-based experiment; conceptual change.

Introduction

Student-centered or active learning privileges the role of collaboration, reflection and discourse as principle methods and goals. The effectiveness of active learning on improving learning outcomes is well documented in the literature (see Freeman *et al.*, 2014). Research in the learning sciences and CSCL has devoted much attention to the design of tools and activities that promote active learning. What is surprising, however, are the barriers that faculty members perceive in the use and adoption of research-based active learning instructional strategies (Henderson & Dancy, 2007).

One approach that has managed to overcome this barrier is *peer instruction* (PI; Mazur, 1997). It is reported to be one of the most widely adopted active learning pedagogies at the post-secondary level (Meltzer & Thornton, 2012; Henderson, 2008). Researchers have documented the benefits of PI (Crouch & Mazur, 2001; Lasry, Mazur & Watkins, 2008), and the impact of variations in how it is scripted (Turpen & Finkelstein, 2009). But there is still much to learn about this pedagogy, how its components might be effectively used differently, and how it might be designed for use outside the classroom. This current research explored the impact of several key features of PI and took up the challenge of bringing it online with the design of a tool called DALITE – the Distributed Active Learning Interactive Technology Environment.

DALITE is a web-based learning platform designed to provide students with an asynchronous version of peer instruction. It is designed to engage students in written self-explanation (rationales), comparison of these rationales to those of peers, and reflection on the quality of rationales (thumbs-up) along with comparison of rationales to that of an expert. DALITE is intended to be part of an active learning pedagogy and allows the course content to follow students outside of class. Through a unique database of student-generated answers and rationales, students share their understandings with peers asynchronously. Activity in DALITE starts with the class being provided with a DALITE assignment, usually a series of 3-5 conceptual questions. Individual students can then log into the system using a computer or mobile device. Each time a student answers a question they are asked to provide a written rationale. The student-generated rationales become part of the DALITE database, and eventually are used in the DALITE *script* for future students. DALITE assignments provide teachers with the opportunity to see what their students are thinking, either before or after classroom instruction. We elaborate on this script later.

In this paper we report on the results of this design-based research project and what was learned from the experience. In particular, we focus on the efforts to design DALITE to promote reflection and discourse, and promote construction of conceptual knowledge - i.e., conceptual change. Additionally, we add our findings to the growing body of principles for design of CSCL-inspired tools, particularly those related to asynchronous methods for engaging students in learning activities.

Theory and background

Findings on active learning pedagogies show strong improvements in students' conceptual learning (Freeman et al., 2014; Meltzer & Thornton, 2012) and a better adoption of discipline-based thinking (Van Heuvelen, 1991). A recent meta-analysis by Freeman, et al., (2014) provides a comprehensive and up-to-date review of the results of active learning.

While there are different models of conceptual change (Chi, Slotta & deLeeuw, 1994; diSessa, 1993; Vosniadou, 1994) evidence suggests mechanisms that promote the process, these include: intentional reflection (Sinatra & Pintrich 2003), self-explanation (Chi, et al., 1994), compare and contrast tasks (Bransford, Franks, Vye, & Sherwood, 1989). The common features of these methods is the reflective and discursive practices that each tap into, in their own way. Equally, the value of such socio-cognitive and socio-cultural practices has been examined in other areas of research in the field of CSCL (Stahl, 2006).

In the past ten years there has been a proliferation of active learning techniques that tap into this literature and that have emerged at the elementary and middle school levels - e.g., inquiry based science, learning by design. However, active learning approaches have been less structured at the post-secondary level and have relied on the general notion of collaboration.

Peer instruction

A major feature of PI is the potential for discussion and debate between students with opposing viewpoints. Implementations of PI generally follow a script similar to think-pair-share (for details of the PI script see Mazur, 1997). Some of the most successful implementations of PI have been those found in university settings that involve large lecture halls, with hundreds of students, supported by teams of teaching assistants (TAs). Rich discussions can arise in such settings because of the increased probability of students with diverse views. In addition, many of the successful examples have the benefit of TAs to monitor conversations and to create more effective student pairings – i.e., more diverse viewpoints. If the success of PI is based on this diversity then what happens in smaller classrooms, or when budgets limit the number of teaching assistants? Equally, if PI depends on all students having equal opportunity to express their view or join the discussion what happens when some students choose not to participate or are silenced by social factors involved in group dynamics? These are some of the questions that the design of DALITE attempts to address.

Summing up what we wanted to learn from DALITE

The current iteration of DALITE was conceived as a way to harness the benefits of PI and address some of its missed opportunities. In traditional enactments of PI, students' reasoning is seldom recorded, save the chance overheard conversation or if the instructor intentionally calls for explanations. As such, it is difficult to know what types of arguments and reasoning are convincing to students, and which elements of an argument might move students towards or away from the correct answer. In addition, until now, there has been no systematic documentation of the rationales used by students to arrive at an answer to conceptual questions. Therefore, there is no way of knowing what could be learned from how students' responses might help to shape more effective conceptual questions. Additionally, might there be different effects regarding the timing of assigning questions, might there be an issue of the context of delivery or the wording? Can we promote better forms of *intercontextualization* (Engle, 2006) with the sequencing and design of questions?

In this study we attempted to look at these questions along with the bigger issues of whether or not DALITE's design promotes reflection and discourse, and conceptual change. In the next sections we describe the three-year project, briefly, then some of the results that have implications for the design of future learning environments.

Methods

DALITE used a *design-based research* (DBR) methodology. DBR is a pragmatic and iterative approach to educational research that allows researchers and pedagogical designers to examine the conditions and context that surround the implementation and use of an innovation. Anderson and Shattuck (2012) describe DBR as consisting of six main features: (1) situated in real educational contexts; (2) focuses on the design and testing of

significant innovations (e.g., pedagogical approaches, instructional tools and systems) that are theoretically based; (3) generally spans a period of several iterations of the innovation; (4) a collaboration between researcher and practitioners; (5) uses mixed methods for data collection; and (6) involves evolution of design principles, thereby adding to the understanding of educational theory. This current research adheres to these six features, in particular, it used a mixed methods approach to data collection.

Context

DALITE is a project conducted by a research team at three English-speaking colleges in Quebec, Canada. In all iterations, it was implemented in a calculus-based mechanics physics course, equivalent to a typical undergraduate freshman physics course at university (sometimes called *gateway*), though the pacing is somewhat slower because of a 15-week semester. Students were of diverse cultural backgrounds with a majority having a language other than English as a first language. The majority of students were first year science majors between the ages of 17 - 19, enrolled in one of two science profiles – Pure and Applied or Health Sciences. In all cases, participants were from the regular stream, which means their high school grades in the science and math prerequisites are between 70-90%. Typically, the gender distribution in these programs is between 1:1 and 1:2 ratio (male:female).

Data collected

The data collected for this project used mixed-methods. Qualitative sources included the DALITE databases, classroom observations, and both student and teacher interviews. At each development phase, these data were used to help describe under what circumstances DALITE worked best, and when it did not. At each point, these data informed future design decisions. In addition to the qualitative data, we also collected pretest-posttest data from the Force Concept Inventory (FCI; Hestenes *et al.*, 1992). It is a 30-item multiple-choice questionnaire and the most widely used and researched assessment of Newtonian concepts (McDermott & Redish, 1999). All three iterations of DALITE used the FCI as a measure to assess students' learning, and for the purpose of comparison (using a quasi-experimental design).

DALITE's databases

To date, the DALITE Curriculum database contains over 120 questions spread across the three main topics that are generally covered in an introductory physics course – i.e., kinematics, dynamics, and conservation principles (energy and momentum). These questions are designed to be roughly at the first-year university level. Influenced by the Ohio State concept test questions (Lee, Ding, Reay, & Bao, 2011), many questions are organized into sets of three to four questions on a single concept that progressively increase in difficulty. These sets of increasingly difficult multiple-choice problems are built on similar deep structures with different surface features, or similar surface features with different deep structures. While the individual instructor has control over the selection of questions to be assigned to his/her students, the corpus of questions was selected by the team of instructors (co-researchers).

The database of student-generated rationales was first developed through a "seeding" process. That is, about 20 students were asked to use a streamlined DALITE script that had them answer the questions and write rationales. This process was necessary so that the first real students using the system could see rationales. This requirement to "seed" the database places constraints on the development of new questions entering the system but was deemed necessary for collecting authentic data. The rationale database was cleaned and nonsense rationales were eliminated (e.g., unreadable text, meaningless strings of symbols). To date there are over 7000 rationales available for the 120 questions with the most populated questions having over 120 rationales each.

History of designing DALITE

First iteration 2010-11

The first iteration began in 2010 as a co-design project with a team of researcher/designers from another institution in Eastern Canada. That instantiation used the open source platform SAIL Smart Space along with tagging capabilities, and built upon the success of studies conducted by Tissenbaum and Slotta (2009). The curriculum was developed using a co-design approach, working in close collaboration with physics instructors at the college-level, where DALITE was enacted regularly throughout a semester in one section of Mechanics with 32 science students. All classes were held in a technology-rich smart classroom environment, an active learning space with a seating arrangement designed to facilitate collaboration.

Design features

Two main ideas steered the design and implementation of the first iteration – adaptive scripting and orchestration (Dillenbourg & Fischer, 2007). To start, there were activities at three levels of social organization - the individual, the dyad and the small group (supergroup). At each level the individual or group was asked to perform four tasks: (1) categorize the type of question by tagging the major elements (element list provided), (2) write a short rationale to explain the choice, (3) answer a multiple-choice question, and (4) write a short rationale to explain the categorization. Each step was scripted in such a way as to encourage students to think about the underlying principles involved in the problem *prior* to solving it (step 1), and then to reflect on why/how this helped them solve the problem (step 3). The first step began as homework (at the individual level), subsequent steps were completed in class (in dyads and supergroups). At the dyad and supergroup levels students were able to view the collective work of the rest of the class (from the homework phase of the activity) in the form of an aggregated histogram of tags and individual reflections. As students moved from one level to the next the questions become progressively more challenging, requiring the thinking of many minds. For a more complete reporting see (Charles, Tissenbaum, Whittaker, Lui, Dugdale & Slotta, 2011).

Second iteration

The second iteration of DALITE began with an effort to modify the original infrastructure to accommodate new constraints and a new programmer. Eventually, the new infrastructure consisted of the following components: (1) a student registration and software application management system; (2) a framework for data mining and tracking of student interactions in real time including the instructional scripts; (3) a locally stored central database or repository; and (4) data displays for instructors. The platform used "Agile" development practices with the aim of ensuring future availability, scalability, and performance. The database repository is composed of two parts: (1) the curriculum content – conceptual multiple-choice questions (sometimes referred to as *concept test* questions); and, (2) the student-generated answers and rationales for these answers.

The important difference between iteration one and two was the changing of the orchestration and the script. In particular, while there was substantial benefit from the in-class work (first iteration) it was too difficult to sustain over the length of the course. Additionally, only one of the two institutions involved had the requisite facilities to adequately implement such an involved active learning curriculum. As such, the in-class portion was removed and the homework script was elaborated. The script continued to put a strong emphasis on the tagging activity and the research team focused on the creation of appropriate tags for the growing question database. Results of this second iteration showed that while students used the tags, they were not sufficiently discriminating between concepts or between categories of questions, which was the intention. Furthermore, when interviewed, students had not recognized how to use the tags or their purpose.

Third iteration

The third iteration, which is the current version of DALITE, continues to use the second-generation infrastructure. Based on the results of the second phase, the tags were removed from the system, but not from the study. Instead, we designed a test of a new form of tag that would be orchestrated in the classroom, which could be more closely scaffolded by the instructor. These tags showed some improvements but are still a work in progress. We do not report on them further in this paper.

Scripting the third iteration of DALITE

In the current iteration of DALITE, students log into the system and are directed to a prepared assignment that consists of sets of questions similar to those used by in-class PI. They are asked to follow the sequence of six steps: Step 1, students <u>select</u> an answer for a multiple-choice question, similar to the first step in PI. Step 2, students select which answer is correct and write a rationale that explains their thinking (Figure 1).

In Step 3, students are asked to <u>reconsider</u> their original answer in the context of rationales for their own answer, and a similar selection of rationales for an alternative answer. This purposeful comparison is designed to provide the variety that is sometimes missing in face-to-face PI. Step 4, students <u>re-select</u> their answer, choosing to stay with their original selection or change, based on the rationales (Figure 2). Step 5, students are asked to <u>vote</u> on most convincing rationale presented (optional step). Step 6, students are presented with the rationale from an expert (teacher) and are encouraged to <u>review</u> their rationale relative to the expert's rationale (Figure 3). Note that the correct answer is not shown to the students, only a correct rationale. It is left up to the student to infer the correct answer and the instructor to follow-up in-class to present the correct answer. There was also an instructor's display interface that allowed DALITE to be brought into the classroom and provides real time review.

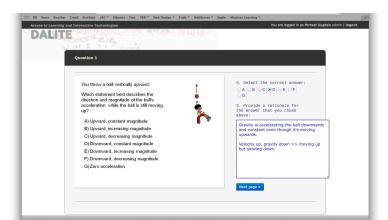


Figure 1. DALITE screens for steps 1 & 2: select, vote and write a rationale.

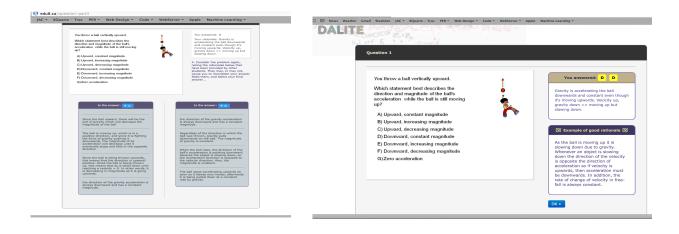


Figure 2. DALITE screens for steps 4.

Figure 3. DALITE screens for steps 6, expert rationale.

Context and participants

In the third and final iteration, DALITE was again implemented as part of a first-year introductory calculusbased mechanics (physics) course. DALITE content questions reflect the three units of the Mechanics course – Kinematics (1DKin and 2DKin), Dynamics (LinDyn) and Conservation principles (Momentum and Energy) and arranged in groupings of three to five questions per assignment.

Observations and data were collected from a culturally diverse student population in five sections taught at three urban colleges by four instructors: (1) College A, one instructor teaching two sections – groups T09 & T10; (2) College B two instructors teaching 1 section each – T07 & T08; (3) College C, one instructor teaching one section – T06. All instructors used an active learning pedagogy but had varying degrees of experience with this practice. The instructor for groups T09 and T10 being the most experienced, having over six years developing the skills required to orchestrate such pedagogy; the instructor for group T08 had the least (less than two years). These differences are taken into account in the interpretation of the results and discussion.

Confirming DALITE's effectiveness

In this third iteration, DALITE students (N=137) were compared to two control cohorts. The first comparison cohort came from a database of 13,422 students who had taken the FCI of which a subset of 2,913 had the same incoming score range as our DALITE sample. This control data was comprised of students taught with a variety of pedagogical approaches and thereby provide an unbiased comparison. A *purposeful sampling* method was used to select cohort 2, the "peer instruction no-DALITE" group. These students were part of two sections, one taught by a teacher in College A and another taught by a teacher at a larger institution of higher education

(N=188). Both instructors had used PI in their classes for several years. Comparison to such a sample is critical and ensures our results are authentic and meaningful.

The results show that DALITE students outperformed this regular control cohort $(0.47\pm0.02 \text{ vs} 0.350\pm0.006; \text{ p}<0.000)$. However, no difference was found in conceptual gain between DALITE students and those who had in-class Peer Instruction $(0.47\pm0.02 \text{ vs} 0.48\pm0.02; \text{ p}=0.84)$. In other words, students using DALITE (n=137) in their college courses do not differ significantly in conceptual gains (p=0.38) from students who used real-time Peer Instruction (n=188). The results show a surprising similarity between four of the five groups and a small difference with a fifth (section T06). Overall differences are between DALITE groups are not statistically significant (g₁ =0.50; g₂ =0.50; g₃ =0.47; g₄ =0.48; g₅ =0.38; p=0.06) with four of the five groups being extremely similar and close to all the variation residing in the fifth group.

Building on DALITE rationales

Sixty-six DALITE questions from the database of 120 were made available to instructors, of which 48 were used across all 5 sections. Total numbers of DALITE assignments ranged between 12 to 15 with totals of 48 to 66 questions, respectively. In each case students were required to answer the question and produce rationales according to the DALITE script described earlier. A total of 6837 student-generated rationales were produced (see Table 1).

Sections	T06	T07	T08	T09	T10	Totals
# students	n=30	n=41	n=36	n=31	n=30	N=168
#Qs. Assigned by instructor	48	50	48	66	66	
Mean #Qs. answered per student	36	40	34	51	58	
Mode #Qs. answered per student	48	50	48	58	66	
% Qs. completed per student	75	80	70	78	88	
Total # of rationales	1081	1637	1206	1235	1678	6837
Avg. length of rationales (z-score avg.)	0.10	-0.51	1.88	1.14	2.26	

Table 1: Descriptive statistics on the rationales generated by students in the five sections, across the 3 colleges.

Of these five sections, T9 and T10 were assigned the most questions with section T10 being unique in that students had the highest completion rates of any section. Note that the same teacher taught sections T9 and T10, and was the most skilled with active learning pedagogy. Interestingly, while students in section T10 had the longest mean rationales, students in section T08 also wrote longer rationales. These trends were investigated, but not reported here.

Learning from DALITE

Is DALITE as effective as PI?

Our results show that DALITE, for this cohort, was as effective as in-class peer instruction (PI), measured by gains on the FCI. These findings are consistent with the instructors' perceptions that DALITE allowed them to replace the time spent on clicker questions (PI) with other group activity.

Did students engage in the DALITE script?

Most students completed the majority of the assigned DALITE questions. The length of an average rationale was in the range of 20–30 words (see Table 1). Questions dealing with linear dynamics (LinDyn) were particularly good at eliciting longer rationales (average lengths were statistically greater) as were graphical questions.

Why did students engage in DALITE?

Twenty-six post-instruction student-interviews were conducted from all five sections. This was a purposeful sampling therefore not all sections had the same number of students interviewed. We selected a range of students, some who wrote long rationales and others who wrote short ones. The interview data provides us with information about the specific features designed into DALITE and how students used them. These data suggest that students were motivated by a variety of reasons. The two most prominent were related to the following DALITE script features: (1) prompting for self-explanation; (2) providing an opportunity to compare with peers.

For instance, students referred to how they were "learning how to learn" when doing their DALITE assignments. In response to the question, Why did you write longer than average rationales, a student answered:

So I was trying to explain it to myself. I wanted to get all the points out and didn't want to leave anything out because I would print out the notes after and study that. So if I only had 2 sentences, I'd go back to it [the notes] and say I don't understand so when I wrote out my thought process when I would go back to it [DALITE]. Next time it would be a lot easier to understand the material. I believe that's why I write a lot.

Other students stated that DALITE provided a low-risk environment. Students were encouraged to express their understandings without the punitive specter of grades and judgement. Recall, there is no right or wrong assessment at the end of the DALITE script, instead students are encouraged to compare their rationale to that of an expert. One student in particular, who wrote progressively longer explanations throughout the term talked about how it encouraged her to express herself:

I think it was my confidence in my physics knowledge towards the end of the course... I was kind of tentative at first. And, I was kinna of like figuring out DALITE, theory, all that's happening. So I would write a little sentence but by the end I was so used to the process and had knowledge so I put everything down, everything I could possibly think of. It's almost [as if] I had lost the fear of being wrong, which is cool... It's like thinking out loud.

Another finding from the interviews was the growing sense of increased self-regulation and awareness of one's explanation. By reading their peer's rationales, some students began wanting to model good explanations both for themselves and others. One student stated that reading "choppy" rationales changed the way she wrote her own.

now I explain the concept behind everything, so I give more detailed rationales.... Since you have to present [your rationale], you have to say "ok this is what we think and why." It organizes your thoughts.

Orchestration of DALITE: How DALITE interacts with other classroom activities

Two instructors (T08, T09 & T10) engaged their students with more writing outside of DALITE (using reflective writing and other activities). Students of those instructors write longer rationales and reported that having the opportunity to explain to themselves in writing helped prepare them for their class discussions. In fact, they state that their in-class discussions were "passionate". Though they worked on DALITE alone, they would discuss their answers and some of their study habits with each other in class. Students in these groups enjoyed the authority the active learning pedagogy and classroom atmosphere provided. As a result, their ways of reasoning out problems together and as a "team" became a way of being: "We were passionate about what we were doing, we wanted to do well, we wanted to do well together." However, this self-regulation seems to need to be supported by other classroom activities. In other words, students engaged in other writing activities valued in the classroom wrote more in DALITE and engaged more with the course materials.

Conclusion

As with all DBR projects, we provide guidelines for design. First, scripting works and can support selfexplanation and reflection. Database questions can produce different levels of engagement (as evidenced by the length of rationales). Most importantly, DALITE can work differently depending on how it is orchestrated. Indeed, although writing ought to be influenced by linguistic proficiency, non-anglophone students were particularly engaged and produced longer rationales in sections where teachers place greater value on writing and pre-class preparation (reflective writing or Flip-JiTT). In short, orchestration is important for its uptake. Orchestration means bringing these activities and artifacts into the classroom and sending them back out, at the same time sending the message that you value both the doing as well as the way that it is done.

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Navigating Connected Inquiry Learning with ScienceKit

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Abstract: New pervasive, social, and mobile technologies hold great potential for supporting young people's connections between interests, peer culture, and academic pursuits. Such connected learning experiences are critical for deep and engaged learning. However, efforts to identify and sustain ways to connect these experiences for learners remain elusive. In this study, we shed light on how we can initiate the process of connected learning through technology-realized and facilitator-based scaffolding of learners' interests, social interactions, and scientific inquiry pursuits. Specifically, we documented three cases of learners in an afterschool program called Kitchen Chemistry and their use of a social media app called ScienceKit. Analysis of ScienceKit data with facilitator interactions reveals a typology of learner paths across connected learning experiences. Furthermore, understanding typologies that best match each learner appears to be critical for helping learners to make connections across interest-driven and peer-supported scientific inquiry.

Keywords: connected learning, educational technology, social media, science inquiry

Introduction

Pervasive, social, and mobile technologies hold great potential to help young people connect their interests, peer culture, and academic pursuits (Ito et al., 2013). Such *connected learning* experiences are critical as research has shown that when learners deeply identify with a discipline, they engage more often (Ito et al., 2013), develop dispositions in those disciplines (Clegg & Kolodner, 2014), and begin to see themselves as empowered contributors to that discipline (Nasir, 2002). To date, immersive and social technologies (e.g., gaming systems, social media sites) that have fueled connected learning have mostly supported powerful learning outside of school and traditional academic disciplines (e.g., Squire, Ben DeVane, & Durga, 2009). Often, efforts to identify and sustain ways to connect these experiences to more formal academic endeavors remain an elusive enterprise (Ito et al., 2013). One key factor in helping forge links between learners' interests and their academics, has been finding ways to balance between offering them flexibility to explore their personal interests in socially relevant ways, while providing more structured scaffolding needed to support their procedural and conceptual understanding within a discipline (Clegg et al., 2012; Ito et al., 2013). Our research engages with the persistent question of how to design for such balance: What technology-based and facilitator-supported interactions promote and strengthen the connections that learners make across spheres of connected learning experiences; specifically their procedural and conceptual understandings of a discipline, personal interests, and peer interactions?

The study reported here is part of our larger design-based research initiative to promote connected learning experiences that we call *life-relevant science learning*, to help learners identify and explore the potential roles they can play in science and to help them find personally meaningful connections to science (Clegg & Kolodner, 2014). Specifically, we shed light on *how we can initiate the process of connected learning through technology-realized and facilitator-based scaffolding of learners' interests, social interactions, and scientific inquiry pursuits.* We examined learners' entries in a social media app called *ScienceKit* that we designed to promote life-relevant science inquiry and facilitate responsive, real-time inquiry scaffolding (Ahn et al., 2014). ScienceKit was specifically designed to help amplify learner dispositions. In previous studies, we found that ScienceKit enabled facilitators to notice learners' interactions and experiences that are often difficult to discern in the physical environment (Ahn et al., 2014). Through analysis of these entries, we sought to understand the role of ScienceKit and adult facilitation in influencing how learners navigated different spheres of connected learning. Our findings begin to articulate the types of scaffolding that are needed – which can come from different sources such as technology, peers, and educators – that promote connected learning experiences, particularly for learners from traditional school environments in which interests and peer culture are often de-emphasized or discouraged (Songer, 2006).

Background: Connected learning framework

Ito et al.'s (2013) connected learning framework guides our approach to scaffolding learners' experiences in life-relevant science learning environments. Connected learning describes a learning process that is driven by personal interests, encouraged with peer support, and helps learners connect their personal pursuits to formal academic and career possibilities (Ito et al., 2013). Interest-driven activities often lead to personal enjoyment, curiosity about unexpected gaps in knowledge, concern regarding a subject matter, and choices to pursue activities that help an individual solidify their identity, life goals, or self-improvement over a longer-term (Edelson & Joseph, 2004). Life-relevant learning seeks to connect academic pursuits, peer-support and personal interest through mindful guidance and scaffolding to maintain a learner's focus.

Peer-support provides a means for connecting learners' interests to scientific inquiry. With networked and mobile technologies, peer-support has expanded from face-to-face interactions among similar-aged learners to also include learners over vast distances and asynchronous communication (Clegg et al., 2013; Ellison, Steinfield, & Lampe, 2007; Kreijns, Kirschner, & Jochems, 2003). These networks differ from prior peer-supports by offering persistent records, searchability, replicability, and an increased reach for communication (boyd, 2009). Such features are valuable tools that afford learners with opportunities to engage in authentic, collaborative inquiry that mirrors scientific practice (Ketelhut, Nelson, Clarke, & Dede, 2010). Social media tools offer personally relevant modes of communication, allowing learners a way to express themselves through a variety of means via new media (e.g., music, photos) (Greenhow & Robelia, 2009).

The academic sphere of learning consists of more traditional disciplinary learning venues such as academic studies, civic engagement, and career opportunities (Ito et al., 2013). We situate scientific inquiry as an academic sphere of learning as inquiry is shaped by standards-based frameworks such as the Next Generation Science Standards (NGSS) (NRC, 2012; NSTA, 2012). Scientific inquiry involves asking questions about the world, searching to understand what is known, recognizing the gaps in one's understanding, and investigating to answer remaining questions (e.g., Clegg & Kolodner, 2014). We can readily design and observe rote steps to scientific inquiry in which a learner follows a predictable series of steps, such as question and answer prompts (which we refer to as algorithmic inquiry). However, science learning environments that focus solely on rote practices can create situations in which learners can become detached or unmotivated to learn the more complex forms of inquiry (Chinn & Malhotra, 2002).

The connected learning framework aspires to weave together these three spheres of learning. However, our understanding remains limited regarding the ways in which we can initiate and strengthen learners' abilities to connect their experiences across these spheres. For example, helping a learner move from a personal interest to a deeper disciplinary practice is a complex process. The converse situation is also difficult in many established academic contexts, where learners may not perceive science as interesting or personally relevant (Chinn & Malhotra, 2002). The result is a rift between academic, interest-driven, and peer supported experiences, which could then pose challenges for researchers and practitioners who help learners engage in connected learning experiences. While Ito et al. (2013) focus on systemic challenges to promoting connected learning (e.g., socio-economic inequalities), we investigate the practical applications of connected learning to identify challenges that arise on a day-to-day basis and ways to address them. We seek to discover ways in which software-realized and facilitator-based scaffolding can help learners navigate effectively across their personal interests, peer interactions, and academically oriented scientific inquiry. Therefore, our study aims to uncover how the artifacts learners captured (e.g., images, video, drawings) through the use of a social media tool (ScienceKit) can inform our understanding of how they connect their personal interests and academically oriented spheres of learning, and shed light on the barriers they may face in this process. When helping learners engage in life-relevant science learning, we must take any rifts across these spheres into account and help learners forge new connections to mitigate them.

Methods

Design approach

We enact Ito et al.'s (2013) connected learning framework by linking children's interests in cooking and eating to scientific inquiry in a social context with peers and adults who share their interests. Learners in our study participated in the Kitchen Chemistry (KC) life-relevant science learning program, an after-school or summer camp program where children learn science and scientific inquiry skills through making and perfecting dishes (Clegg et al., 2012). In KC, learners use the ScienceKit social media iOSTM app that enables learners to capture moments of interest in their daily lives (e.g., cooking) with multi-media (e.g., photos, drawings, videos, and text) and connect them to science inquiry by making claims, posing questions, and designing experiments (Ahn et al., 2014). These learner-created entries are then shared amongst all learners to support social interaction. For

this study, we analyzed learner generated data gathered in the ScienceKit iPad[™] app (Figure 1).

We collected ScienceKit data over three consecutive days (~ 4.5 hours each day) in a weeklong implementation of the KC program that was run in a summer camp serving a lower socioeconomic status (SES) public elementary school. Seven learners (9-11 years old) participated in the camp. Seven researchers and one science teacher served as facilitators in the environment. Including our entire research team as facilitators in the environment ensured full participation of researchers in our design-based research process (Barab & Squire, 2004) and approximated our inclusive, future vision of integrating community volunteers in such programs. We gathered the ScienceKit entry data primarily from learner-created entries, though for some entries facilitators supported data input (e.g., if the learner's hands were full due to cooking activities).



Figure 1. A) ScienceKit allows for posting photos, videos, drawings, and associated text. B) Learners and facilitators can then see everyone's posts on a global timeline. C) Learners used ScienceKit it a variety of situations (e.g., drawing together, recording events from afar).

Context and data collection

On the first day of KC, we explained to learners that they would ultimately conduct their own investigations as chefs, investigators and scientists to perfect a dish of their choosing. We shared our collective goal to connect their personal cooking interests to science learning. Each day we encouraged them to ask and explore questions in which they were personally interested. We also focused on helping learners use ScienceKit to express their interests and explore their inquiry questions. The first two days of the program were semi-structured days in which facilitators provided inquiry questions and helped learners to carry out cooking investigations. On the first day, learners made observations of four batches of brownies and hypothesized about the ingredient or procedure that was changed among the variations. After a discussion of how the number of eggs was varied in each batch of brownies, learners carried out an experiment investigating oil and water miscibility using eggs as an emulsifying agent. The second day's investigations focused on baking cookies with different leavening agents to understand how leavening agents react and the role their reactions play in making cookies. This day concluded with the learners developing their own interest-driven inquiry plan to be conducted on the third and fourth days. Throughout the program, learners used ScienceKit to document their experiences, ask new questions, collect data, and make claims. Learners also used ScienceKit to capture playful, fun, or social moments in the program. For this study, we did not evaluate ScienceKit data on the fourth day as much since the final day was focused more on presentations of their findings to parents and the local school community.

We used methods consistent with a comparative case study (Merriam 1998) on this single implementation of KC. We compared three cases of learners (Juan, Larielle and Aziza, Noah) to examine how connected learning took place in KC through the use of ScienceKit. We collected data from various sources (multiple video perspectives of the learning activities and context, researcher field notes, learner reflections and interviews). For this study, our focus was on analysis of learners' ScienceKit entries. We unpacked the interaction moments that learners captured in ScienceKit themselves to illuminate our understanding of how the children made connections across the spheres of peer-oriented, interest-driven, and academically oriented learning experiences. As such, we analyzed learners' ScienceKit entries using qualitative coding methods (Strauss & Corbin, 2007). We coded each learners' entries for interest, peer-culture, and inquiry attributes. Interest-driven contributions refer to entries that related to or described learners' hobbies, curiosities, or excitement (Edelson & Joseph, 2004). Similarly, peer-culture entries are posts that displayed learners peer interactions (e.g., selfies with one another, interviewing peers) or that reflected common peer practices (e.g., when learners appeared to be imitating pop culture references, language, or inside jokes they had observed of their peers' previous entries in ScienceKit). Finally, we used Chinn & Malhotra's (2002) framework for scientific inquiry to identify scientific practices learners exhibited in their ScienceKit entries. Interest, peer-

culture, and inquiry codes were not mutually exclusive. Drawing on Ito's (2013) vision of connected learning, it was our hope that learners' entries would reflect overlaps in these codes. Coding for each entry also accounted for relevant meta-data (e.g., time the entry was posted, who made the entry, what media if any did the entry use). Next, we conducted an axial coding pass where we identified high-level themes of the ways that learners' interests, peer interactions, and inquiry came together (or remained disparate) in their use of ScienceKit overtime. We also examined how these connections or disconnections were influenced by the ScienceKit app and adult facilitation.

Results

We detail several vignettes of learners' experiences that reflect three distinct paths across interest-powered, academically oriented, and peer-supported connected learning spheres. Our discussion then highlights our analysis of the ways in which facilitator-based and software-realized scaffolding influenced connected learning experiences.

Inquiry to interest and peer support

Our first vignette highlights a learner who made diverse attempts to engage in inquiry and peer interactions, but did not make many connections between these spheres of connected learning. On the first day of KC, Juan, a rising 4th grader in KC, was very energetic during his group's investigation of ways to mix oil and water using eggs as an emulsifier. His attempts to find a correct "answer" for how the ingredients interacted were illustrated in his ScienceKit video entries, which detailed his thought processes, hypotheses, and observations. For instance, Juan stated, "My hypothesis was sort of right, but I think you have to shake [the oil and water to get them to mix]." When a facilitator asked Juan to observe the bottles again to allow the oil and water to sit for a while to see if they were indeed mixed, Juan stated in a ScienceKit video that "You're starting to see the yellow come back. Oh come on, I was wrong!" While looking over the investigation procedures, Juan noticed that we were going to add an egg to the oil and water mixture, and wondered aloud, "If an egg would float on [the oil and water. When facilitators tried to connect to his interest in baby elephants to a movie or television show with baby elephants, Juan ended the conversation and his ScienceKit entry stating "Ah, yeah, that's all I got for now."

Juan did show some interest and connection to peer groups, but did not fully engage these interests and peer groups in his KC inquiry experiences with ScienceKit. For instance, he attempted to connect with fellow learner Allen by referring to an earlier comment Allen made in ScienceKit about a "cookie monster" as the learners were baking cookies to explore various leavening agents. Juan related to Allen's post by making his own post about a "cookie master." However, Juan's outreach to his peers did not result in an exchange between learners in ScienceKit. While Juan continued to use ScienceKit on the second day to create inquiry-related posts, his posts did not reflect algorithmic inquiry as they had on the first day of KC. Instead, Juan continued to make posts connected to what he found interesting at the moment, such as stating his drawing of a cookie was a "cool cookie". However, he did not connect to interests he may have had external to KC. By the third day, Juan drastically reduced his use of ScienceKit, resulting in only 5 posts compared to the first day's 27 posts.

Analysis of Juan

Juan's use of ScienceKit suggests that it was difficult for him to connect an academic focus to his pre-existing interests or peer-groups. Initially, Juan was actively engaged in the scientific inquiry process, as seen when he stated factual observations and engaged in algorithmic scientific inquiry during the pre-planned investigations. He also playfully expressed himself during inquiry projects and when using ScienceKit in general. However, it was difficult for facilitators to uncover what Juan's personal interests were, and how they might be connected to inquiry. Without apparent connections between his academic pursuits, interests, or peer interactions, facilitators' scaffolding within ScienceKit largely focused on Juan's inquiry practice as it was an area that he seemed to be more willing to share with facilitators. Effectively, Juan's ScienceKit use focused mostly on engaging in pre-planned scientific inquiry. We suspect this may be because Juan missed the introduction to interest-driven inquiry on the first day. Missing this key discussion, coupled with the more rote academic practices and culture that he was familiar with in a more traditional classroom, may have impacted Juan's willingness to share his interests and connect his peer interactions to inquiry. *Our analysis of Juan's case suggests that learners' interests may not initially be apparent, thus making it difficult for facilitators to connect their interests to inquiry and peer-oriented experiences.*

Peer-culture to interest

Our next vignette describes two learners, Larielle and Aziza, friends who initially used ScienceKit to navigate

from peer-interactions to interest-driven inquiry before facing challenges with their peer-oriented inquiry. On the first day of KC, a fellow learner, Demarco, started taking photos of other learners during a whole group discussion. Larielle and Aziza quickly imitated Demarco's posts during the meeting, taking photos of facilitators and peers. Such peer-oriented posts were common from Larielle and Aziza throughout KC, whether it was during social time or formal inquiry activities. The girls also often shared ScienceKit on one iPadTM for inquiry tasks. As a result, their inquiry tasks were increasingly distributed on Larielle's ScienceKit account.

During inquiry-based tasks, Larielle and Aziza often created videos in ScienceKit by interviewing one another about what they were doing in KC. For instance, one interview occurred over the course of two ScienceKit videos for a total length of 20 minutes. Aziza recorded the inquiry and interviews throughout the entries. Both learners were focused on strengthening their group identity while using ScienceKit. For instance, they started the video by stating, "Welcome to table #4, people. Here is [Larielle] and here is our friend here" when introducing Larielle and the facilitator at the table. Aziza then reviewed the four different brownies they were investigating, asking her partner questions such as, "So [Larielle], [...] how is brownie #1 looking?" Both girls crafted their video as an interactive, interview-like dialogue on the brownies and measurement tools. Midway through the video, the facilitator helped scaffold the inquiry by prompting them with questions such as asking them to compare two brownie variations. Eventually, Larielle and Aziza even started making predictions about how the brownies were made both with help from the facilitator and independently.

On the second day, Larielle and Aziza worked with their science teacher from the previous year, Ms. Smith. One of the facilitators directed the interview and ScienceKit in each of their interview-style videos on this day. Thus Aziza, who had been operating ScienceKit for the group on the first day, was not able to direct the camera on her specific interests. The content of the interview also changed when the facilitator conducted the interview. The group used ScienceKit as they made observations of three variations of cookies made with different leaveners. When asked whether they thought all groups were measuring the size of the cookie dough once it had been placed on the baking sheet, Aziza stated "kinda". However, when the facilitator prompted her for clarification, she revised her answer to "well, I think they are doing the same." Aziza then shifted to asking the facilitators answered these questions, which redirected the focus of the inquiry back to the facilitator rather than Larielle and Aziza. This exchange reflected a marked reduction in the amount of peer-interaction that was visible in the girls' ScienceKit interactions during the second day of inquiry sessions Their subsequent entries also became more passive as Larielle and Aziza often propped the iPadTM on a bookshelf with ScienceKit recording "hands-free" video of their interactions rather than using it for peer interviews.

Analysis of Larielle and Aziza

Our analysis of this vignette suggests that social learning technologies can have a positive impact on learners' ability to connect with their peer-groups while engaging in scientific inquiry. With Larielle and Aziza, the practice of interviewing connected their peer-group to interest-driven inquiry. When the facilitator prompted the child interviewer with questions, s/he was able to help the learners use ScienceKit to reflect on the inquiry-based aspects of their experiment. However, once the facilitator more actively assumed the interviewer role to encourage specific lines of inquiry, Larielle and Aziza began to use ScienceKit more passively. Larielle and Aziza seemed to lose interest in the immediate inquiry when they were no longer conducting interviews as a peer-group. *This change in usage seems to suggest that facilitator-provided scaffolding could unintentionally steer learners away from peer-supported inquiry and decrease engagement with the learning technology.* We suspect that working with their teacher may have also impacted the power dynamics of Larielle and Aziza's group compared to the first day, reinforcing an emphasis on academically oriented inquiry. Moreover, as the learners became less actively engaged with the inquiry process, they also seemed to become less engaged with ScienceKit. We hypothesize that ScienceKit was no longer part of Larielle and Aziza's peer-group, resulting in Larielle and Aziza's of their interests while using ScienceKit as a peer-group.

Interest to inquiry

A third path we observed involved facilitators who focused on navigating learners toward the academic sphere while scaffolding interest-driven inquiry. During the first day of the program, learners were frequently prompted to draw upon personal curiosity to ask new inquiry questions during planned inquiry activities as well as during downtime. One such example of spontaneous, interest-driven inquiry occurred during breakfast on the first day. As learners were acclimating to ScienceKit, they carried their iPadsTM to the breakfast table. One learner, Noah, snapped a photo of strawberries on the table and made the ScienceKit entry, "Some [strawberries] probably got more care than others. Some are bigger than others." In a later post, Noah posed a question about whether milk had sugar as an ingredient, using a photo of a milk-carton with attached meta-text. Noah then began to explore

the questions he posted by reviewing the ingredients lists (or "nutrition") on the wrappers of his breakfast foods (e.g., milk, cereal). As other learners began to see Noah's posts in ScienceKit, they began to post their own similar questions.

Noah's other entries on the first day of KC also reflected a focus on interest-driven inquiry (rather than peer support). He would often go into great detail when exploring the semi-structured inquiry projects, such as when he commented "How much they each rose [brownie #4] 1 inch, [brownie #2] 1 inch, [brownie #1] 1 inch, [brownie #3] half inch" or when he stated "Maybe [the brownie variation labeled] B3 needed to be in the oven long enough to rise higher. B3 is shorter than the rest." While Noah did not document his peer-oriented inquiries as much as others, he did post many factual observations and shared important algorithmic inquiry.

On the second day of KC facilitators encouraged learners to capture as much of their cooking experiments as possible using ScienceKit. Likewise, we observed that Noah's ScienceKit posts increased. However, his posts on Day 2 consisted mostly of photos or videos of what they were doing in the program (e.g., mixing ingredients) as opposed to inquiry-based reasoning about the experiences he was capturing (e.g., making claims, asking questions). While Noah still created posts that displayed his inquiry-based reasoning practices, the amount of such posts were relatively the same as in the previous day (4 posts showing algorithmic inquiry compared to 5). Additionally, Noah's Day 2 posts consistently lacked visible peer-interactions or connections with others in the group. When Noah was given the opportunity and support by facilitators to create his own inquiry, he did derive his inquiry question from personal interest. Noah's own investigation involved exploring variations of his mom's meatloaf recipe so that he could later share his results with her. Noah continued to carefully document his inquiry-based process the next day (e.g., with posts describing the consistency of the various meatloaf recipes prior to cooking).

Analysis of Noah

Throughout the KC program, Noah consistently demonstrated his ability to engage in interest-driven inquiry, from the questions during breakfast on the first day to engaging in a more complex inquiry when conducting his meatloaf investigation. However, Noah did not connect his inquiry to peer-groups in KC. Scaffolding on Day 2 may have influenced Noah's use of ScienceKit to focus more on the academic sphere instead of finding ways to encourage a connection to peer-groups that happened serendipitously during breakfast on the first day, when he seeded questions to his fellow learners. Facilitators also noted that Noah was a more introverted learner, which may have affected the number of peer-oriented ScienceKit posts that he made. Based on the ways in which Noah's questions propagated to his peers early on in the KC program, it may have been helpful to acknowledge Noah's ability to create new interest-driven inquiry topics and encourage him to engage more with peer-groups (e.g., helping fellow learners to create more complex inquiry) to further his connected learning experiences.

Note that the context of KC activities may have influenced the type of ScienceKit entries that Noah made. During Day 1, instead of cooking, learners made observations and claims about pre-baked brownie variations. During Day 2, learners were actively engaged in experiment processes (e.g., measuring and mixing ingredients), with less time to make observations and claims about their results. On Day 3, learners engaged in their own interest-driven inquiries. Day 3's data for Noah reflects the strongest connection between academically oriented and interest-powered spheres, as he was deeply invested in a cooking investigation to recreate and improve upon his mother's meatloaf recipe. Using Noah's strong interest and ability to create inquiries from those interests came close to complex scientific inquiry, but lacked peer-support. His case suggests that *connecting less socially prone learners to others may be challenging, but simply exposing their inquiry practices to others may facilitate social exchanges*.

Discussion

Our analysis of a practical application of Ito et al.'s (2013) connected learning framework underscores the importance of being attuned to the interactions and influences that learners, facilitators, and technological tools exert within in a connected learning context. While social learning technologies can help minimize disconnects between interest-driven and peer-supported spheres for learners, the gaps between these spheres and learners' academic pursuits, remain non-trivial to traverse. A key take-away from this analysis is that ScienceKit afforded us a rich data channel to help identify, follow, and strengthen learners' connections across academically oriented, interest-driven, and peer-supported spheres of influence. The findings from our study underscore the ways in which social media-based tools and associated learner data illuminate our understanding of the paths that learners can follow across academically oriented, peer supported, and interest-powered contexts. Importantly, these data also shed light on potential barriers and missed opportunities that researchers and practitioners can use to initiate and strengthen connections across the interrelated, but often disconnected, spheres. For example, our analysis of Noah revealed that he had a fairly high degree of personal interest in

inquiry (e.g., unprompted observations about strawberries, ingredients in milk, designing new variations on his mother's meatloaf recipe). Facilitator efforts to reinforce his knowledge of academically oriented scientific procedures (measuring, mixing, comparing) seemed to be beneficial. However, facilitators could have taken advantage of the data in Noah's ScienceKit stream to quickly connect the academically oriented, process-based artifacts he created on Day 2 to his personal interests (seen on Day 1). Furthermore, facilitators could have devised opportunities for Noah to showcase his personally relevant meatloaf investigation with peers, thereby strengthening the peer-supported sphere of his connected learning network.

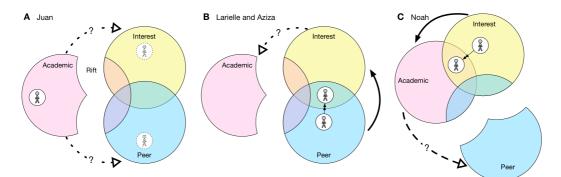


Figure 2. This figure depicts situative learner practice based on Ito et al.'s connected learning framework, (2013) and potential difficulties encountered by different learners. Though similar in shape, it is not intended to be two dimensional or representative of a Venn diagram. A) Juan's interests and peer-support were difficult to connect to his focus on academic activities. B) Larielle and Aziza's path moved from peer support to interests but transition to formal academic inquiry were challenging. C) Scaffolding helped Noah to create interest driven inquiry but did not help him connect to peer-support groups with his inquiries.

Another key take-away is that the ScienceKit data, coupled with analysis of facilitator-learner interactions, revealed the beginnings of a typology of learner paths across connected learning experiences specific to Kitchen Chemistry. Our analysis has revealed a variety of possible paths that learners may take as they develop more comprehensively connected learning experiences (Figure 2). It appears that not only can there be a rift between the academic sphere and the interest and peer-support spheres as previously described, but there might also be a similar gap separating peer-support for learners such as Noah (Figure 2C). Understanding what typology best matches each learner could be critical for helping learners engage in using a new learning technology for interest-driven and peer-supported scientific inquiry, specifically in connected learning contexts such as Kitchen Chemistry. Researchers could use such a typology to evaluate the efforts of learners to effectively engage in connected learning. The typology might also inform new designs for connected learning experiences themselves. Both of these findings contribute to our understanding of individual learner paths within connected learning experiences, and suggest design implications for strengthening the ways in which learners traverse across the spheres of connected learning.

Overall, our analysis points to the potential of more complex social tools and focused reflection of educators to ascertain learners' natural orientations within academic, peer-oriented, and interest-driven spheres and to make decisions about how to direct them toward more connected learning. For example, during the Day 1 activity, the scientific inquiry practices that we foregrounded were making observations and proposing claims about experiment results. Facilitators asked the learners to examine four batches of brownies and to try to determine what ingredient might have been varied to cause any differences in physical characteristics, such as texture, taste, density, color. The learners were explicitly asked to engage in academically oriented inquiry. During the next 2 days, KC activities required more active engagement by learners in the actual cooking process. Learners captured these activities both because they wanted to and because they were encouraged to do so. We believe it is difficult to tease apart whether facilitators directed learners or whether learners wanted to capture everything. With reflective practice (Schön, 1983) facilitators and technology designers should also reflect on the logical intent and purpose of actions. Facilitators may have needed more time and better tools (in ScienceKit) to review and reflect on the media captured during these activities to connect procedural practices to inquiry-based practices. Future work can focus on developing social inquiry technologies to make such learner interest and peer-interactions in the current science camp setting as well as community contexts easier for facilitators to recognize in real-time. Additionally, research into social inquiry technologies should support more adaptable scaffolding to help learners navigate connected learning paths, thus empowering learners to connect to

their interests and peer-groups.

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Materiality of Online Students' Peer-Review Activities in Higher Education

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Abstract: In spite of the widespread use of technology in higher education, discourses on learning technologies commonly account for their features as disembodied from their use. There have so far been few theoretical approaches that have delved into "the technology question" in CSCL. We present an empirical study that investigates how students' peer-review activities are entangled with sociomaterial aspects of mediated collaborative learning. The students' peer-review activities were analyzed according to *the Collective Instrument-mediated Activity Situation* (CIAS) model, and findings show that the materiality of two different tools had considerable influence on how students engaged with the texts and how they interacted with each other.

Keywords: peer-review practices, web-based commenting tools, technology, higher education, learning, design, socio-materiality.

Introduction: The technology question in CSCL

Technologies matter. They are not neutral (Haas, 1996; Säljö, 2010; Rabardel, 1995), but "imbued with history and values" (Haas,1999:209). Yet, in the field of technology in education, most research refers to technology either as a "glass box", transparent to the user and not altering learning or our understandings of our learning practices in any significant way or as a "black box", all-powerful, self-determining and having "one-way" effects (Haas, 1996). As a consequence of such view on technology, little attention has indeed been paid to its material properties (i.e. "the arrangement of an artifact's physical and/or digital materials into particular forms that endure across differences in place and time and are important to users" Leonardi, 2012:161). The sociomaterial nature of technology and its concomitant role in enacting change in our learning practices has so far been overlooked (Johri, 2011; Sörensen, 2009). Drawing on recent conceptualizations of "CSCL artifacts" (Stahl et al. 2014; Overdijk et al. 2012) and the instrumental perspective on CSCL systems (Rabardel and Bourmaud 2003; Lonchamp, 2012), this paper addresses the question of technology while taking heed of its materiality, in this case embedded in higher education institutions. We argue thus for an approach able to describe how students' peer-review is bound to the material characteristics (affordances) of the artifacts in use and intertwined with peer-review practices accepted and legitimated at their educational institution. The aim is to address the constitutive entanglement of material and social aspects of CSCL artifacts in collaborative learning and in particular students' peer-review practices. Within CSCL, the interest for the imbrication between material and social aspects of human activities is not really new; questions pertaining to the material aspects of human activities have been the object of attention within, for instance, the cultural historical approach (Vygotsky, 1934/1997); Scribner and Cole, 1981; Engeström, 1897; Rabardel, 1995; Nardi and Kaptelinin, 2006; Säljö and Wyndhamn, 1993). These concerns and questions about the role played by technology in education have recently been renewed and conceptualized by Johri (2011); Sörensen (2009) and Fenwick et al. (2011). Sörensen in particular has pointed at "a blindness toward the question of how educational practice is affected by materials" and how these materials are much more than mere artifacts to advance educational performance (Sörensen, 2009:2). Such understandings of sociomaterial aspects embedded in CSCL practices seem to resonate with Pierre Rabardel's (1995) instrumental genesis approach as introduced into the CSCL community by Lonchamp (2012).

In this paper, we will first introduce the contribution of the sociomateriality perspective to the understanding of contemporary forms of collaborative learning as introduced by Johri (2011), Sörensen (2008) and Fenwick et al. (2011). Second, we present the *Collective Instrument-mediated Activity Situation* (CIAS) model (Rabardel, 1995) for the analysis of sociomateriality in CSCL practices. Third, we describe the empirical study investigating how does the design of online commenting functions of social tools (i.e. Google doc and WordPress) come to embody university students' online peer-review practices? To this end, we focus on students' electronic comments and their reflections post-experience. Third, we report our findings particularly looking at how emergent multiple instrumental mediations, established during peer-review, are on the one hand, bound to the materiality embedded in the design of the tools' features and on the other hand, present

implications for the inner organization of students' peer-review activity. We conclude with a brief discussion on the role that a sociomateriality approach can play in the field of CSCL.

Sociomateriality and CSCL practices

The technology question introduced by Haas (1996) in the field of literacy, refers to the relationship between technology and materiality that we consider be at the center of our CSCL practices. In our view, learning becomes material through the use of technologies and this materiality has implications for the development of "human culture and the shape of human consciousness" (Haas, 1996:4). In the field of CSCL, Haas's technology question brings us to study the sociomaterial perspective on learning (Johri, 2011; Sörensen, 2008; Fenwick et al. 2011). This perspective has mainly drawn from research on science studies conducted by scholars such as Latour (2005), Barad (2003), Knorr Cetina (2001), and in the field of education by Engeström (1987, 2001) and Miettinen et al. (1999). Its main tenet is that learning, which is situated in the material world (i.e. classrooms, worksites, virtual spaces, community projects, social movements, and so forth), is sociomaterial as its "energies, processes, motives and outcomes are fully entangled with material practice, knowledge representations (e.g. text, pedagogy, curriculum content) nature, time, space, technologies and objects of all kinds" (Fenwick et al. 2011:vii). Such a conception of sociomateriality conveys an understanding of learning that is situated and embedded within an activity, context and culture (Lave, 1988) and bounded to the artifacts making such activity possible (Vygotsky, 1997; Rabardel, 1995; Nardi and Kaptelinin, 2006). It refers to learning as everyday practice where technologies are at a central position between the individual learner or teacher and the cultural practice within which learners and teachers as individuals operate (Lave, 1988; Wenger 1998; Stahl and Hesse, 2009; O'Malley et al. 2009). Moreover, a perspective on sociomateriality questions the idea of treating CSCL technology as a given and disembodied from aspects pertaining to learning practices that technologies embody in its design and are enacted when they are used. A focus on the sociomaterial invites us to dig into the heterogeneous and multiple relationships that assemble and configure contemporary CSCL practices.

Analytical framework

One of the analytical models within the sociocultural tradition that seizes the technology question in CSCL is the one proposed by Pierre Rabardel in his conceptualization of the instrumental genesis approach (Rabardel, 1995). This approach is built around the concepts of *instrument* (a mixed entity constituted by the constraints and potentialities of the artifact and the subject with her knowledge and former habits), instrumental genesis, and artifact's instrumental field (Lonchamp, 2012; Ritella and Hakkarainen, 2012). Central to this conceptualization of instrument is the notion of *utilization scheme* designating a cognitive structure that describes an invariant organization of behavior for a given class of situations including both technical and conceptual aspects (Lonchamp, 2012). Such structure underlies the inner organization of mediated human activities and constitute the social, behavior part of the instrument whilst the artifact, the technical or material part. Rabardel distinguishes two sub-process in the development of the instruments: the *instrumentalization* process that is *artifact-oriented* and concerns the evolution of the artifact, material side of the instrument and the *instrumentation* process, *subject-oriented* and relative to the emergence and evolution of the utilization schemes.

Two analytical models are proposed by the instrumental genesis approach, of which the Collective Instrument-mediated Activity Situation (CIAS) model is of particular concern here. The CIAS model consists of four poles: the subject, the other subject(s), the tool and the object of the activity and distinguishes between two kinds of subject–object mediations: i-the *epistemic mediation* oriented toward comprehending the object, its properties and evolution, and ii-the *pragmatic mediation* oriented toward the transformation of the object and the achievements of the results. Building on the work of Cerratto Pargman (2003) and Folcher (2003), Rabardel and Bourmaud (2003), distinguish the *interpersonal mediation* between subjects that may also be epistemic or pragmatic in nature depending on whether it is a question of knowing the object or transforming it. Finally a fourth mediation is introduced as the subject also relates to herself (Rabardel and Samurcay, 2001). This latter is called *reflexive or heuristic mediation* and aims to explain how the subject manages her activity in relation to her goals, means, resources etc.

These four instrumental mediations may or may not be established during CSCL activities. Their establishment and development will depend on how the user deals with and adapts to changes introduced by the tool, and how well the user succeeds in transforming and approaching the artifact. The strength of the model is the identification of emergent mediations that constitute themselves from the imbrication of the materiality of the artifacts in use (its design rationale) and the sociocultural organization of human activities (subject's representations and utilization schemes).

Methods

Context and participants of the study

A qualitative study comprising 12 recruited bachelor students (10 males and 2 females) using online web-based commenting tools was set up in May 2012 at a department of Informatics at a Swedish university. The purpose of the study was to understand how undergraduate students appropriate online web-commenting tools in their peer-review tasks. Students were divided into 2 groups of 6 participants each who in pairs discussed 6 texts, consisting of students' own early drafts of bachelor theses (e.g. 4-9 pages). Each text had two authors (as it is accepted at the institution studied), and two reviewers made comments. For commenting, half of the groups used Google docs (GD), and the other half used Wordpress (WP). The crucial difference between the two systems is that the commenting function in GD allows the reviewer to directly anchor the comment in the text while the one provided by WP offers instead a common writing field at the end of the document. These tools were selected because of the learning promises associated to online collaborative annotations tools in higher education (Su et al. 2010; Glover et al. 2007).

The respondents were enrolled in a mandatory course aimed at scaffolding students in their academic writing. Central to the course is the review of others' bachelor drafts. Most students perform their reviews using the university's in-house developed Learning Managing System (LMS). Using the LMS entails students i-respond to a list of pre-formulated questions that embody peer-review criteria accepted at the chosen institution and ii- grade different key sections of the text reviewed. As such students' peer review (before introducing GD and WP) presents a summative character, is private between the reviewer-author, and is organized around providing feedback and/or answering questions (Aghaee and Hansson, 2013).

Participants' peer-review tasks

Three texts from three groups were posted on three different blogs in WP, and three groups uploaded their texts to GD. Two reviewers critiqued each text and the pair of authors of each draft could reply to the critique for the duration of the review phase (72 hours). The reviewer pairs were not the same as the author pairs. Each participant had two assignments: i) giving critique and ii) discussing the critique given.

Data collection techniques

We collected both interaction and reflective data. Interaction data consisted of participants' written comments (153 comments). Reflective data consisted of focus group discussions (80 min with 10 participants) and questionnaires (11 out 12). The interaction data was analyzed according to principles for the analysis of verbal interactions (Cerratto-Pargman, 2003). Responses to the questionnaires and transcriptions of the focus group were analyzed using Graneheim and Lundman's (2004) method of qualitative content analysis.

Coding schemes for data analysis

The data collected was analyzed with the CIAS model. The unit of analysis chosen was students' comments and students' self-reflections on their use of online web-based commenting tools in peer-review. The instantiation of the instrumental mediations emerging from the data was conducted in the following manner:

- *Epistemic mediations* were understood as those relationships oriented toward the comprehension of the content of the text to be reviewed. More precisely, epistemic mediations were identified from the analysis of the *function* of critique given (see table 1).
- *Pragmatic mediations* were understood as those relationships oriented toward the transformation of reading the text into the writing of the critique. More precisely, these mediations were identified from the analysis of the *forms* of the comments (e.g. anchor, compound, detached).
- *Interpersonal mediations* were understood as those relationships oriented toward the interaction with the other. These mediations are identified from the *amount*, *length* of the comment as well as *type* of exchanges generated (e.g. minimal, complete).
- *Reflexive mediations* were understood as relationships oriented toward one-self, intending to manage the own individual activity within a collaborative effort. These mediations were identified from the semantic analysis of the transcriptions generated from the discussion during the focus group and the answers to the questionnaire post-study.

The electronic comments generated by both commenting tools were coded in terms of initiative-only comment and exchanges. Exchanges were further coded based on 1-*type*, 2-form and 3-function. 1-Type was distinguished between minimal (e.g. initiative-reactive) and complete (initiative-reactive-evaluative); 2-Form was distinguished among anchored (inserted in the text), compound (inserted and highlighted in the text) and, detached (disassociated from the word, sentence or paragraph being commented). 3-Function consisted of the following categories (see table 1). These categories were identified according to the ultimate purpose of the peer-review critique given. They were identified from the iterative analysis performed on participants' comments and exchanges (not established a-priori).

Conceptual critique (CC)	addresses the quality of the thinking underlying the text and the construction of the arguments written.
Form and structure (FS)	addresses how the text is put together, the order of the sections, subsections and overall structure of the text.
Cohesion and coherence (COCO)	addresses how the different parts of the text are linked together and how they make sense.
Textual errors (TE)	points out at minor elements as specific faults in the text, like spelling errors or omitted words.
Overall critique (OC)	focuses on providing an overview of the text and may contain elements of all other categories in one comment. It is often presented as a short report.
Non-critique (NC) entails any	comment, which discusses topics outside of the text itself. It may be comments regarding the critique process or social comments of various kinds.

Table 1: Categories for the analysis of the critique conveyed in the comments

Findings

From the different types of relationships that were instrumented with both commenting tools GD and WP in the students' peer-review, we observed the emergence of interpersonal, epistemic, pragmatic and reflexive mediations. These instrumental mediations accounted for both, *material* characteristics (affordances) of the different commenting functions (that were reflected in the amount, type, form and function of the students' comments) and students' *utilization schemes* underlying the organization of their peer-review practice. More specifically, we observed that the materiality of the tools had implications on the *function* (purpose) of the critique as it differed according to the online tool used. With GD, students focused more on "form and structure" and "textual errors" whilst with WP they focused more on "cohesion and coherence" and "overall critique".

Moreover, interacting with both tools reflected the presence of a specific peer-review organization students enacted in their activities. We refer in particular to students' peer-interaction that was organized in initiate-only comment and/or minimal exchange indicating the presence of utilization schemes bound in part to i-characteristics of the commenting tools constituting GD and WP but also to other features previously and commonly used (i.e. university's LMS, MS word, e-mail) and, to ii-students' particular understandings of what performing an academic peer-review entails at their educational institution (i.e. tacit knowledge conveyed through instructions, assessment criteria, discussions at research seminars, feedback from supervisors, thesis defense). Students' peer-review critique also reflected a colloquial, informal character that deviated from the formal tone that is often chosen in the students' peer-reviews performed in the university's LMS (Aghaee and Hansson, 2013). Such a deviation introduced confusion in some occasions. We elaborate on these findings from the four instrumental mediations instantiated from the analysis of the data.

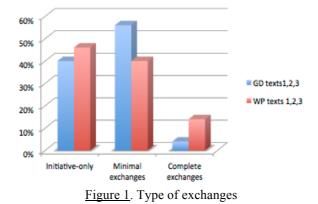
Interpersonal instrumental mediation

A macroscopic view of this mediation shows that the amount of comments (interpreted here as an indicator of interactivity between authors and reviewers) with GD was of 97 with a median length of 16 words. 56 comments were made in WP, with a median length of 40 words. Taking into account that the 12 respondents were involved during 72 hours, the degree of interaction between respondents seems low independently of the tool used. Firstly, this might be due to the synchronicity afforded by the tools that was deviated and thus instrumentalized in an asynchronous mode of interaction by students' peer-interaction. In this sense, the students in their activity attributed a different function to the interactivity mode afforded by the tools. Secondly, such an instrumentalization was certainly due to students' previous experiences of interacting asynchronously with peers

in their academic peer-reviews. The asynchronous property attributed to the online tools might be due to students' needs to organize their peer-review according to pre-existing social, behavioral invariants underlying the organization of the interactions between the students vis-à-vis the text and, vis-à-vis the reviewing task to be accomplished.

Furthermore, the use of GD encouraged more exchanges than WP but shorter in length; whilst WP promoted less exchanges but longer in length. Reviews conducted with GD presented a higher number of *minimal* exchanges whilst WP presented a slightly higher number of *complete* exchanges. These differences can be explained in relation to the quotations (copying) of paragraphs under discussion that students were re-writing in the blogs (WP). The length of the exchanges in WP can be related to reviewers' necessity to recreate authors' sentences (and thus to write more) in order to make sure the semantic context of the detached comments in the blog was available to the authors. The design of WP disregards in fact the location of the comments in relation to the text (i.e. section, paragraph, sentence, word) being commented. As such the reviewers contributed with their comments to connect detached (critique) note with text being critiqued.

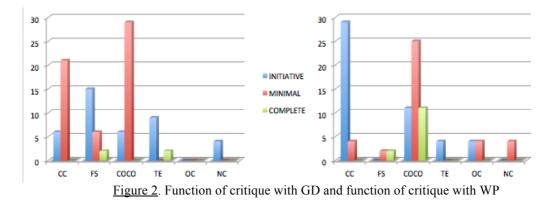
These results can be seen in relation to students' previous and established practices of peer-review associated to specific asynchronous tools such as the university's LMS, E-mail and MS Word and students' mode of interaction most often organized around question-answer. As such, this observation accounts for students' needs to change the instrument (instrumentalization) and their utilization schemes (instrumentation) as they attempt to organize their interaction on a question-answer basis rather than on a argumentative discussion.



Epistemic instrumental mediations

The materiality of the commenting tools mattered. For instance, the amount of comments on "conceptual critique", were higher in WP than in GD. Functions such as "form and structure" and "textual errors" were prevalent on GD whilst "overall critique" dominated in WP. The category "cohesion and coherence" was predominant with more comments on both tools. It was also the category that contained the most minimal exchanges in GD, and the most complete exchanges in WP. This difference probably stems from having different thresholds of effort facilitated by each of the tools used. GD makes it easier for an author to respond while commenting, as the dialogue is embedded in the text being commented. In WP, responding to comments is more cumbersome as the dialogue is detached from the text.

These results reflect differences in the students' ways to engage with the texts that had implications on how they understood the peer-review activity from their interaction with the online commenting tools.



Pragmatic instrumental mediations

Transforming the object of the peer-review activity (i.e. composing comments in order to improve the quality of the other's text), pointed to differences between how the comments were composed on both tools. Comments composed in GD were *anchored comments* – directly inserted in the paragraph or word being discussed-. As such, their topology made it easier to understand what the critique was pointing out. Comments in WP were *detached notes* that topologically speaking were not connected with a particular paragraph or word but with a more general understanding of conveyed ideas. In addition, comments composed in GD were in the form of *compound annotations*, consisting of both an anchor (highlighted text) and textual content (the comment) – or a reply to another of comment. GD also allows participants to only highlight text, or to make a comment without a highlight, but commenting without highlighting did not happen during the study.

During the focus group, students explained it was central for them to communicate their critique as clear as possible in order to facilitate author's comprehension of what the critique was specifically pointing out. The material characteristics of the commenting features in GD appeared to encourage short, concise comments on specific, local parts of the text. Since the comments are placed right beside the text, the tool let reviewers begin adding their comments immediately during their very first read-through. WP's commenting function is instead placed at the bottom of the text. This compels the reader to read through the complete text before leaving the first comment. This was one of the major issues the students brought up during the focus group discussion, stating that it felt silly commenting on minor details when the comments were topologically speaking completely disconnected from the text.

The materiality of the commenting tools encouraged participants to engage differently with the texts under review and then to critique them dissimilarly. Students using *compound comments* commented on more sections of the texts but their comments were succinct and local in relation to students' *detached notes* who commented on fewer sections of the texts, but with a larger number of words and with a more global or holistic approach. Comments with GD were embedded in the text promoting a narrow context for the critique (i.e. the context was the word, the sentence, or a paragraph). In comparison, comments with WP presented a broader context (i.e. the whole text or sections of the text) encouraging students to recreate the relation between comments and focus of the critique provided.

Reflexive instrumental mediations

During the focus group, the students explained that most of them often print the texts to be reviewed so they can work off-line, highlighting, making annotations on paper and then reviewing their comments, structuring, organizing them and rewriting those they will send to the authors via the university's LMS platform. In this sense, students mentioned that great part of the review is done first privately, off-line and then it is communicated to the author. With the use of GD's and WP's commenting functions the private, off-line phase of the peer-review was apparently absent.

Moreover, students mentioned that they were unsure and some confused about the new possibilities the commenting tools were bringing to their peer-review process. Some questioned the idea of discussing academic critique: "Does one discuss critique in a an academic peer-review process?"; "We have learned that one should only accept feedback and do not discuss it". They perceived that commenting tools were shaping the peer-review with a dialogic format some of them were skeptic to adopt as they mentioned they usually do not discuss or socialize around critique that is given. The use of emoticons in the comments was also source of discussion among the participants as some argued that such an element might sometimes influence the direction of the ongoing discussion.

Furthermore, 5 out 10 students commented on the distraction that reading others' critique can introduce in their own reading and understanding of what they consider important to comment on. Three students expressed concerns about "becoming influenced by others' voices on the text under review"; Student A mentioned: "one changes the level (of the comment) because of group pressure". Student B" you are inhibited by seeing others' comments. You only see what is already commented on and may struggle to find your own things". These concerns may be seen as conflicts students experienced in their interaction with online commenting tools that came to challenge established reviewers' utilizations schemes bound to tools lacking a social and synchronous dimension. Engaging with an open peer-review opened thus questions pertaining to social and public aspects of critiquing texts in relation to students' own understanding of what academic critique entails at their educational institution.

Implications

Beyond commonalities and differences observed at the level of the comments produced with the different online commenting tools investigated, this study sheds light on the type of relationships CSCL artifacts mediate. More importantly, the study shows how instrumental mediations emerge from the imbrication of sociomaterialities of collaborative learning practices such as peer-review.

In particular, materiality of the commenting tools in use or previously used had implications on i- how students engaged in with the text and transformed it as well as on ii-how their interaction with the other(s) and with oneself was organized. More precisely, the peer-interaction observed, was mainly based on initiative-only comments and minimal exchanges. This specific organization in the students' interaction reflected the presence of a utilization scheme underlying the activity of peer-review that does not disappear with the advent of new tools. At the opposite, students' utilization schemes associated to peer-review were challenged but not completely destabilized. Students' schemes of utilization were challenged by the synchronous, open and public character of the tools studied but not completely destabilized as the underlying organization of their peer-review practices (e.g. question-answer interaction) was maintained. Students' utilization schemes accommodated to the new conditions opened by the online commenting tools that led the development of instrumentalization processes (Rabardel, 1996). For instance, the synchronous mode of interaction was diverted into asynchronous interaction and the lack of a feature establishing the connection between critique and component of the text critiqued in WP, conducted reviewers to created it through establishing a semantic connection between comment and text being commented (i.e. students make use of quoting- rewriting- that in turn contributed to longer comments structured in some occasions, in complete exchanges). Such changes in the artifact, material-side (instrumentalization) and the subject, social-side (instrumentation) become observable as they were i-enacted in reviewers' behavior (type of peer-interaction) and ii-bound to the affordances and constraints of the tools in use (i.e. anchored, compound and detached comments).

Finally, the study contributes to show that sociomaterial aspects of CSCL practices are necessary to embrace in order to gain a deeper understanding of the relational, dynamic and complex ties between learning and technology (Chaiklin and Lave, 1996). Such an understanding will be beneficial for better seizing the changes that learners and teachers interacting with contemporary technologies enact in their daily learning experiences (Dewey, 1938/1998) and practices (Lave, 1988; Wenger, 1998).

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Research Questions and Research Methods in CSCL Research

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Abstract: While research questions play a critical role in research, their role has seldom been examined systematically. In this study, we examined what kinds of research questions are addressed in CSCL empirical research and what is the relationship between research questions and methods, in part using outcomes of an earlier analysis. The analysis showed that CSCL research has mainly focused on design and implementation of technological and/or curricular interventions. Research questions influenced research methods to a degree, although the relationships were not strict. The results confirmed, as well as contradicted, some of the intuitive conceptions about the relationship between research questions and methods. Implications for future CSCL research are discussed.

Keywords: research questions, research methods, CSCL, relationship

The scientist is not a person who gives the right answers, she's one who asks the right questions (Claude Lévi-Strauss) I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail (Abraham Maslow)

Introduction

The progress of a field is often judged based on the validity of empirical findings generated in the field, but the kinds of outcomes we find in our research are inherently tied to the kinds of question we ask. Research questions direct our attention to particular aspects of phenomena and/or influence the kinds of methods we choose to answer the questions. At the same time, research questions are also often determined and/or constrained by the methods available to us because it is not possible to answer questions without proper methodology. Despite their importance, relatively little attention has been paid to the kinds of research questions in recent empirical investigations of CSCL and how they are related to research methods used to answer the questions.

Research questions

Research questions bridge and connect what is known and what is unknown. Research questions organize our research activities. We use research questions to determine the appropriateness of data collection and analysis methods and evaluate the relevance and meaningfulness of results (Onwuegbuzie & Leech, 2006). By understanding what kinds of research questions are being asked, we can understand where the field is headed (Moore, 1993). Research questions are often distinguished from research problems or research goals (Creswell, 2007; Johnson & Christensen, 2008; Onwuegbuzie & Leech, 2006). According to Johnson and Christensen (2008), a *research problem* is an issue or dilemma within the broad topic area that needs to be addressed or investigated (e.g., lack of learner motivation in online learning). A *research purpose or objective* follows from the research problem and specifies the intent of the study such as whether it intends to describe variable relationships, explain the causality of the relationships, or explore a phenomenon (e.g., whether to search for causes or seek a remedy). A *Research question* is a statement of specific inquiry that the researcher seeks to address (e.g., whether lack of motivation can be reduced in certain conditions). A *Hypothesis*, unique to quantitative research, is a formal expression of the research question.

CSCL emerged as a result of the efforts geared toward understanding how learners learn together with the help of digital technologies. There is a great diversity in research questions being asked in CSCL. Over the years, CSCL research has helped us to understand, for example, that collaborative learning is not a recipe, media effectiveness is a myth, a greater resemblance to face-to-face interactions is not necessarily better, and structuring communication is a subtle compromise (Dillenbourg, Järvelä, & Fischer, 2009). A number of researchers, however, recently raised concerns about gaps in CSCL research, arguing that the field as a whole has emphasized the cognitive dimension of learning too much and neglected the role of affect; lack of research on institutional contexts of CSCL has also been raised (Arnseth & Ludvigsen, 2006; Dillenbourg et al., 2009; Kirschner & Erkens, 2013). There are a number of different ways to examine the kinds of questions that the

field as a whole has been asking. We may ask what drives our research questions, that is, whether they are motivated by theoretical or practical concerns. Some research questions seek proof of concept (e.g., can this work?), whereas others aim to test the effect of a design or variable. One may also evaluate research questions in terms of whether they require quantitative and/or qualitative outcomes to address them and/or whether they are socially relevant and responsible (Roschelle, Bakia, Patton, & Toyama, 2011). Although these are all meaningful and useful typologies, in this paper, we examined which aspects of domain knowledge have been addressed in CSCL research, that is, whether CSCL research questions are directed toward understanding learning processes, outcomes and/or interventions.

Research questions and research methods

Research questions influence or even determine the kinds of answer we get (Maslow, 2002; Suthers, Lund, Rosé, Teplovs, & Law, 2013). This is in part because the way we ask questions determines the method we use to answer those questions. Questions often dictate the methodology needed to answer the questions so that questions about causal relationships of variables lead to experiments, whereas questions about correlational relationships of variable relationships and/or about contextual factors often lead to descriptive studies. Similarly, questions about learning outcomes requires the collection of data that can reveal student performance on exams or other kinds of measures that can show the interim or end product of learning.

The relationships between research questions and methods have been generally conceived in relation to the research objectives, that is, whether the research aims to achieve quantified or qualitative understanding. According to Onwuegbuzie and Leech (2006), for example, quantitative research questions tend to be very specific in nature and deal with descriptive (e.g., what are high-school graduation rates?), comparative (e.g., what is the different between elementary and middle school students' math abilities?) or relationship questions (e.g., what is relationship between variable A and B?). Within the quantitative tradition, survey or descriptive designs are typically used when describing correlational relationships, but experiments are the method of choice when determining causal relationships among variables (Shadish & Campbell, 2002). Qualitative questions, on the other hand, may be open-ended, evolving, and non-directional. They seek to discover, explore or describe processes and experiences. They typically describe, rather than relate variables or groups, and tend to address "what" and "how" questions (Yin, 2009).

Although there is a view that certain methods are inherently superior than others (Becker & Geer, 1957; What Works Clearinghouse, 2010), appropriate research methods are likely to vary depending on the research problems and questions (Onwuegbuzie & Leech, 2006; Trow, 1957). The exact nature of these relationships, however, has never been systematically examined in CSCL research. In this paper, we are interested in understanding whether research questions about certain aspects of CSCL learning (e.g., questions of CSCL outcomes) are studies with certain methods more so than with other methods. For example, do research questions about CSCL outcomes tend to be studied more with certain methods over others? Or do research questions about collaboration processes require the collection of certain data types and analysis method? By examining these relationships, we hope to understand more clearly how research questions interact with research methods and what the resulting relationships mean.

Current investigation

This paper aims to address two questions. First, what kinds of research questions have been asked in recent CSCL empirical investigations? Second, what are the relationships between research questions and research methods? In order to answer the first question, we used content analysis and categorized research questions in terms of whether they address learning outcomes, process, or CSCL interventions. In answering the second question, we relate the analysis of research questions to the results of a prior study. Jeong, Hmelo-Silver, and Yu (2014) analyzed the research methods of published empirical investigations of CSCL between 2005 and 2009. They coded CSCL research methods along four dimensions—research design, settings, data types, and analysis—and found that CSCL researchers employ a diverse set of methodology in their research. In order to explore how research question types and dimensions of research methods. In the current study, we focus on studies between 2005 and 2008 due to the availability of question coding results. Note that this is part of an on-going project that examines CSCL research practice comprehensively. Analysis of additional years and aspects of CSCL research are ongoing.

Methods

Journal and paper selection

Papers were selected first by choosing relevant journals and then selecting appropriate papers from them (Hrastinski & Keller, 2007). In this study, we chose representative CSCL journals by surveying 16 CSCL community leaders (e.g., CSCL committee of ICLS and the editorial board members of ijCSCL). Based on their responses, we selected the following seven journals: (1) *International Journal of Computer Supported Collaborative Learning* (ijCSCL) (2) *Journal of the Learning Sciences*, (3) *Learning and Instruction*, (4) *Computers and Education*, (5) *Journal of Computer Assisted Learning*, (6) *International Journal of Artificial Intelligence in Education*, and (7) *Computers in Human Behavior*. 1,422 research articles were published in the seven journals during the 2005-2008 periods. We selected 310 empirical CSCL investigations using the following criteria: Learning needed to be collaborative and supported by technological tools, but as long as parts of the learning process involved interaction (e.g., collaborative discussion after individual study), it was considered collaborative (see Jeong et al., 2014 for additional details about the selection criteria and process; Due to space limitations, the full list of these 310 papers are not provided here, but are available upon request).

Analysis

We combined content analysis and qualitative descriptions to analyze research questions and methods of CSCL empirical investigations. Coding categories for the content analysis were developed using a combination of inductive and deductive approaches: They were initially developed based on a combination of several top-down schemes (e.g., categories drawn from the submission descriptors of the 2005 CSCL conference) and later refined inductively in the process of coding. The coding categories used in this study are reported below. 20% of the papers were checked for reliability. Cohen's Kappa for all coding categories was all above .75.

Research questions

Research questions were categorized into one of the seven categories, some with sub-codes: (1) Conceptual, (2) Methodological, (3) Process, (4) Outcome, (5) Learner characteristics, (6) Interventions, (7) Other (see Table 1). Coding into multiple categories was allowed when the paper addressed more than one research questions.

Question codes	Code descriptions
Conceptual	Developing/testing conceptual framework and/or refining/testing theoretical constructs/models.
Methodological	Assessment instrument, analysis methods, or design tools or processes.
Process	CSCL processes that can be about (a) collaborative processes (e.g., argumentation), (b) general, often individualistic learning processes (e.g., conceptual change), or (c) other processes related to CSCL (e.g., participation frequency, help use).
Outcome	CSCL outcomes that can be about (a) knowledge outcomes either at the individual or shared/collective level (e.g., knowledge building), (b) skills, (c) non-cognitive outcomes (e.g., perceptions, motivations, attitudes, etc.), or (d) miscellaneous.
Learner	Individual differences and learner characteristics (e.g., gender differences, individual
characteristics	differences in help-seeking).
Intervention	CSCL interventions that can be (a) instructional (e.g., curriculum development, scripting)
	and/or technological (e.g., mobile technology, representational tools).
Other	Questions that did not fit one of the above categories (e.g., parental involvement, community network structures).

Table 1: Coding categories for CSCL research questions

Research methods

Research methods were coded along four dimensions: (1) Research design, (2) Setting, (3) Data, and (4) Analysis. Research designs were coded as (a) Experimental, (b) Descriptive, or (c) Design-based method. Research settings were coded as (a) Laboratory, (b) Classroom or (c) Other settings. Data were coded as (a) Process (e.g., text-messages, video, log data), (b) Outcome (e.g., multiple-choice, open-ended artifacts), and (c) Miscellaneous (e.g., self-report questionnaires, interviews). Analysis methods consisted of three general categories: (a) Quantitative (e.g., code-count, inferential statistics), (b) Qualitative (e.g., Conversation Analysis), and (c) Mixed-analysis (see Jeong et al., 2014, for coding details).

Findings

CSCL research questions

As can be seen in Figure 1, a small portion of CSCL research addressed theoretical or methodological questions (3% and 7% each). Although these studies included data, often in the form of examples, they mainly addressed theoretical (e.g., how to conceptualize the institutional impact of CSCL) or methodological questions (e.g., development of rating scheme for interaction quality). Close to half of the methodological papers were about content analysis addressing issues such as coding scheme development (Meier et al., 2007), unit of analysis (Strijbos & Stahl, 2007), or validity and reliability of content analysis (Beers et al., 2007). The rest of the methodological questions addressed issues such as statistical solutions to multi-level analysis (Cress, 2008), Social Network Analysis (Martine et al., 2006), asynchronous discussion data mining (Dringus & Ellis, 2005), or mixed-method (Schrire, 2006).

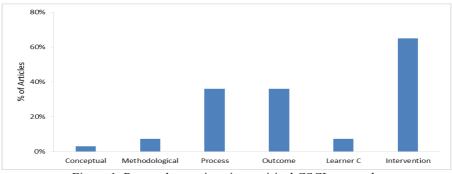


Figure 1. Research questions in empirical CSCL research.

Process questions were addressed in 35% of the studies. Most of them (80%) posed questions about collaborative processes, including collaborative learning and problem solving (e.g., Schwarz & Groot, 2007), linguistic and communication processes such as grounding or chat confusion (e.g., Fuks et al, 2006), or social processes such as group dynamics or development (e.g., Guldberg & Pilkington, 2006). The rest of the process questions (20%) dealt with miscellaneous processes such as system use or coordination processes in CSCL (e.g., Erkens et al., 2005), along with generic learning processes such as conceptual change (Parnafes, 2007). Questions about CSCL outcomes were addressed in 36% of the studies. About half of them (52%) examined knowledge outcomes, but these were mostly outcomes at the individual level. Only a small portion of studies (11%) posed questions about group-level outcomes such as collective knowledge building (e.g., van Aalst & Chan, 2007). Relatively little attention (13%) has been paid to skills such as collaboration skills or critical thinking skills (Rummel & Spada, 2005), but close to half (46%) examined a variety of non-cognitive outcomes such as students' and teachers' perception of the environment, motivation, or attitudes (e.g., Bergin et al., 2007). The remaining papers (6%) examined miscellaneous outcomes such as ethical behavior and accuracy of peer assessment (e.g., Sitthiworachart & Joy, 2008).

The dominant question in CSCL research (65%) was about interventions. Most (76%) focused on technological aspects of CSCL interventions such as the effect of a software agent as a learning partner or the use of ITS to support collaborative learning (e.g., Holmes, 2007). About one-third of intervention studies (31%) examined instructional interventions such as effects of new curricular activities (e.g., Smith & Reiser, 2005) or assessment schemes (e.g., Lee, Chan, & van Aalst, 2006) within the contexts of CSCL. These questions were studied with a focus on the intervention itself (e.g., situating a specific CSCL application across different academic disciplines) as well as in relation to their effects on student learning processes and outcomes (e.g., whether a chat tool decreases 'chat confusion', comparison of different CSCL applications on the discussion process). A small proportion (7%) of studies were interested in understanding *learner characteristics*. These include individual differences in help-seeking, communication styles, or gender differences in CSCL (e.g., Cho et al., 2007).

CSCL research questions and methods

In this section, we consider how research questions are related to various dimensions of research methods. To simply the analysis, we focused on the papers that asked one of the three most frequent CSCL research questions, that is, intervention, process, and outcome questions (N=127). The analysis showed that although

descriptive designs were dominant in studying all three types of research question, different questions tended to be studied with different research designs (Table 2). Questions of CSCL process and outcomes were both likely to be studied in a descriptive manner, whereas intervention questions relied more on experimental designs. Design-based research was largely used to study CSCL processes and interventions.

Questions	Descriptive	Experimental	Design-Based	Total
Process	28 (80%)	3 (9%)	4 (11%)	35
Outcome	12 (80%)	3 (20%)	0 (0%)	15
Intervention	43 (56%)	22 (29%)	12 (16%)	77
Total	80.84	28	16	

Table 2: Research questions and design

Research questions are also associated with analysis methods (Table 3). Reliance on quantitative analysis was strong for all research questions as reported in Jeong et al. (2014), but the degree varied across the questions. Although outcome questions exclusively relied on quantitative or mixed methods, process and intervention questions relied more on mixed and qualitative methods. Research questions were also related to data collection, that is, the kinds of the data collected in the study. Process questions were more likely to be associated with the collection of process data such as text messages or video. Outcome questions relied on data such as pre- and post-test questions, but also on self-report and/or questionnaire data. Intervention questions relied on a roughly equally frequent distribution of process and outcome data. Unlike other dimensions coded, research settings do not seem to be related to research questions, at least at the level of questions coded in this study. Across all questions, classrooms were the dominant setting, followed by laboratory and other settings, indicating that questions of causal relationships are no longer restricted to studies in laboratory settings.

Table 3: Research questions and design

Questions	Quantitative	Qualitative	Mixed	Total
Process	15 (29%)	11 (31%)	9 (26%)	35
Outcome	10 (67%)	0 (0%)	5 (33%)	15
Intervention	27 (35%)	19 (25%)	31 (40%)	77
Total	52	30	45	

The relationships reported above suggest that there are some connections between research questions and methods, we should also bear in mind that the relationships are not entirely deterministic. For example, Mirza, Tartas, Perrer-Clermont, and de Pietro (2007) studied graphical tool use for argumentation. Their approach was descriptive and the analysis described an example of learning activity mediated by the software with a focus on knowledge construction and argumentation processes. Although the analysis relied on some coding and counting (e.g., of meaning-making oriented units), the main part of the analysis were qualitative characterizations of two argumentation maps (e.g., whether and when a moral dimension became a focus of discussion) and how each map evolved over turns. On the other hand, Lund, Molinari, Sejourne, and Baker (2007), adopted an experimental approach as they also studied students' use of argumentation diagrams. They compared two conditions, one in which student pairs used the tool as a means for debate and another in which they used the tool for representing debate. Graphs generated during the debates were analyzed using an elaborate coding scheme called ADAM (Argumentation diagram Analysis Method), which produced debate and difference scores. Statistical tests were also carried out to identify main factors for studying argumentative graphs and to compare the two experimental conditions. These two studies both shared similar, overlapping questions about the same kinds of graphical argumentation tools. They even collected and analyzed the same type of data (i.e., argumentation maps). Yet, they adopted different study designs and analysis methods so that Mirza et al. relied on a descriptive case study and described how the tool are used in the process of meaningmaking more or less qualitatively, whereas Lund et al. focused on comparing different instructions accompanying the tool and attempted to quantify the impacts. So, while certain question tended to be studies with certain methods, research questions does not appear to constrain research methods in any inherent way and a diverse methods have been applied to study different aspects of CSCL.

Conclusions and implications

Not surprisingly, our results suggest that questions in CSCL empirical research have mostly been focused on examining technological and/or instructional interventions of CSCL, often in connection to learning processes and outcomes. These represent important areas of CSCL and it appears that the field is trying to lead the way in innovating technological and curricular interventions and examining them in connection to learning processes and outcomes. At the same time, the results also raise questions as to whether CSCL research is overly driven by technological interventions and/or whether adequate attention has been paid to other important aspects of CSCL, such the role of teachers or other mechanisms for facilitating productive knowledge building. In this sense, our analysis confirmed some of previously identified concerns such as that there were few studies that addressed institutional contexts of CSCL (Arnseth & Ludvigsen, 2006). Although our coding categories did not have a separate code for it, we did not find these captured in the *other* questions category. In addition, although learning in CSCL environments involves changes not just in individual learners, but also in groups or communities (Cress, 2008; Stahl, 2013), few studies addressed learning at the collective level. This is likely to change with newer analytic techniques found in more recent studies, but we need to be mindful of examining CSCL at multiple levels and/or from multiple perspectives. Although it appears that affective or non-cognitive dimensions of CSCL have received a fair amount of research attention judging from the kinds of questions and data collected, there have been few attempts to examine them deeply. Moreover, studies that attempt to integrate cognitive and social mechanisms of CSCL were rare but this is an area that we anticipate will change as we continue our ongoing analysis of more recent research.

Our analysis found that research methods did vary depending on the research questions, although the coupling between the two was loose. Research methods do not automatically follow research question in one path, and there are different methods for pursuing similar questions. This is good news, especially considering recent attempts at crosstalk between different methodological traditions (Suthers et al., 2013) and can serve as a basis for research synthesis. However, the relationship between research questions and method is not arbitrary. Research questions do constrain research methods to some extent. The constraints may be inherent in the questions and/or method at least in certain cases, but they may also originate from our own biases in the kinds of questions we ask and methods we are familiar with. As the productive multivocality project demonstrated, we also have much to learn from each other (Suthers et al., 2013). Through a collaborative effort on common data sets, researchers from different disciplines engaged in effectively expanding their repertoire of both questions and methods. Further research is needed to understand more clearly the nature of these relationships. This will likely involve understanding the inherent methodological mandates of certain research questions and/or methods and overcoming our deep-rooted biases and experimenting with new research topics and methods. It will also involve a further examination of a selection of papers in terms of how they define the problems and justify the selection of the methods. It is unclear yet how the results of the study can be used to guide the choice of research methods, but we hope that our goal opens these issues up for further discussions and help us better understand what we ask and how we seek answers to our question.

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Students' Design Decisions in Collaborative Design of Location-Based Games for Learning

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Abstract: This paper describes a study of students designing location-based games for each other to learn history. A learning scenario was developed where groups of students create a game, receive and play another group's game, and create a media product based on their experiences. We analyse the video footage of students collaboratively engaged with designing the games and highlight how the design process involves making practical decisions, and how the notion of the *others* – the students' peers – feature in the group's interaction. Furthermore, the analysis focuses on how the design process is coordinated and collaboratively organised, and involves translation of the source material into game information.

Keywords: Learning through design, location-based games, history learning, video analysis

Introduction

This paper addresses how upper secondary students make design decisions and coordinate their work when participating in a learning scenario involving collaborative design of location-based games for learning about history. A learning scenario was developed in collaboration with a history teacher where groups of students create a game, receive and play another group's game, and create a media product based on their experiences in the previous activities. The analysis of the video-based empirical material shows how the students engage creatively with the learning material and describes the interactional organisation of the process of designing games for another group of students. We further address the students' practical accomplishment of game design and how engage in a design process where they integrate curricular and other historical source materials, and place these in a narrative by constructing a number of points of interest in the location based-game. They are thus taking into account historical events, the layout of different locations, the playability of the game, and the actual game mechanics supported by the location based-game authoring tool. The location-based gaming experience was intended to feed into the creation of a media product that enables students to demonstrate their learning experience.

One of the goals for the scenario was to put students in a position to work *creatively* with the available resources by creating products (a game and a presentation), using a game authoring tool for mobile, location-based games, rather than reproducing curricular material. The students were allowed a great deal of freedom in choice of historical sources to work with. The game they designed was to be used by their peers.

The organisation of the paper is as follows. First, a literature review focusing on use of games for educational purposes, mobile and ubiquitous technology in the field of CSCL is presented. Then, the learning scenario including student activities and the main technology they used is accounted for. Next, we present the research methods used. Then we present our analysis of transcripts of student activity, and how the activity can be understood. Finally, we discuss the implications of our analysis.

Designing mobile, location-based games for learning

The use of mobile technology to support collaborative learning has a history within the field of CSCL (e.g., Roschelle & Pea 2002; Roschelle, Rosas & Nussbaum, 2005). Tools have been developed and studied, both to support collaboration in the classroom (Chang, Wang, Chen & Liang, 2009; White, 2006), and to provide support when moving into the field (Lyons, 2009; Yatani, Sugimoto & Kusunoki, 2004; Tan, Liu & Chang, 2007). Computer games have also become increasingly used and studied for their educational potential (e.g., Kickmeier-Rust & Albert, 2012; Shute, Rieber, & Van Eck, 2011), also within the field of CSCL (e.g., Ke, 2007; Rosenbaum, Klopfer, Broughner & Rosencheck, 2007; Satwitcz & Stevens, 2007; Klopfer, Perry, Squire, Jan & Steinkuehler, 2005; Bennerstedt & Linderoth, 2009).

Much of the orientation in the scholarly literature on educational games is on various learning effects of students *playing* computer games. Similarly, many of the educational initiatives towards design and creation of computer games concern computer game design in itself, rather than using the game design process for students to learn other curricula (Orvieto, 2012). One example that looks at both is El-Nasr and Smith's (2006) two case-studies of students in computer science learning computer skills through modifying, or *modding*,

existing games by working with the game engines. They found that game development involves many different skills other than programming, ranging from artistic to mathematical concepts. Lim (2008) raises the idea that students in school should be allowed to design their own computer games based on their own interpretations of the curriculum as a way to create more engagement with their own learning processes. Prensky (2008) argues that one way for educational games to be successful is that the students create such games themselves. In particular, he suggests that students create what he calls "*mini-games*" (Prensky, 2008, p. 1006). These mini-games are made by groups of 2-3 students doing their own curriculum-based research with an advisor, and usually take around one hour to complete. Resnick (2007; Resnick, et al., 2009) describes Scratch, which is an online system where students learn to program interactive, online media products such as games, stories and animations, designed to foster creative and systematic thinking. In a study where twelve to thirteen year old students used Scratch to modify the mathematics game *Gem Game*, Garneli, Giannakos, Chorianopoulos and Jaccheri (2013) found that this activity increased interest in programming, although they did not find that the modification activity had a visible effect on mathematics performance.

Schwarz and Stoecker (2012) describe the process of *Learning Game Design* as a relative new craft where game design and didactic design are combined. The design of a learning game potentially involves a number of activities, including story-, visual-, sound-, interaction-, information and character design. Sharples, et al. (2014) argue that storytelling is a promising approach to support learning, and one that can aid students in creating meaning from the abundance of available learning resources. Suitable for combining with virtual worlds, augmented reality or games, storytelling builds on the navigation of resources and can help with adding coherence to learning experiences.

The game design learning scenario

To explore the creative design of location-based games for history learning, a scenario involving different digital tools and activities was designed. The scenario, which took place in the classroom and out in the city of Bergen, comprised three overall activities: Game creation, Game playing, and Media Product development. First, working in groups, the students tied historical themes in Bergen's history to actual places in Bergen, and combined these places and themes into a location-based game. Second, the students gave their game to another student group to play. Third, after playing another group's game game, each group re-created their experiences with the different themes in the game into a media product. Most, but not all of these products were digital, combining images, video and sound captured while playing the game.

Through game creation, the students identified and combined features of the real world, represented by the different locations in the city, and their interpretations of the different written sources available to them, into a game narrative that would be discovered by the recipients as they played the game outdoors. The gaming aspect was about finding the locations in the game by following clues in the narrative. By creating a media product, the students were put in a position to reflect over and demonstrate what they learned about Bergen's history by playing another group's game.

Theme for the games: WW2 in Bergen

The scenario was designed and planned in close collaboration with the teacher, both in terms of the theme chosen and how to use the available technology for creating and playing the location-based games. The participating teacher taught history, and was the "e-contact" at the school with expanded responsibilities related to the school's ICT-systems, and helping the other teachers with digital technology. She chose Bergen history during the 2nd World War (WW2) as the theme for the game as 1) it fit with the current curriculum, which was between "older" and "newer" history, 2) the school building was occupied by the German military during WW2, and 3) the availability of physical locations related to the theme around Bergen. The teacher identified themes and events related to 16 locations in Bergen during WW2. Examples of the themes include: 'The attack on Bergen on April 9th, 1945. Where?', 'The Printed Press of Bergen during times of crisis: Illegal papers', 'The history of Jews in Bergen', and 'Food and rationing'. The scenario comprised three phases:

• *Game Design Activity:* The class was divided in half, with each half being given a list of eight of the themes. Each half was further divided into groups of three to four students. Each group was tasked to choose a minimum of six of the themes and events, which would form the basis of their game. How they ordered the locations in the game, how they assigned a theme to a location, and what they chose to write about each, was up to them. They were also free to discover and create locations and themes by themselves. A set of documents was made available to the students at the beginning of the scenario. These included a description of the tasks, a list of learning goals, a description of how the scenario was tied to the five basic competencies (a key aspect of the most recent reform of Norwegian education),

information on assessment criteria (students were graded on their participation including collaboration and end product), a list of resources and internet-based sites with relevant historical source material, and a user manual for SILO, the authoring tool for location-based games. A collection of historical sources relevant to the theme, such as magazines and books was made available in the classroom, and the students were also encouraged to use local museums, the public library of Bergen, and the school library, and also to visit the sites physically.

- *Game Playing Activity:* Each team was to play the game they received, moving around Bergen and learning about the historical sites in the game. The students were encouraged to bring cameras with them, or to use the cameras on their private mobile phones, and record various aspects of the places that they visited so they could use it as source material for creating a media product after having completed the game. Exactly how they chose to do this was discretional.
- *Media Product Development*: The media product the students created after playing the game could take the shape of a video or film, a wiki or a blog, or a web page. Based on previous observation of game play, it was decided that the creation of a media product would not interfere too much with the fun aspect of playing of the game, yet at the same time increase the learning potential of the game. As the game application paused automatically when they were at each site, knowing they would have to include the location in their digital media product was intended to increase the attention they paid to the site.

Technological resources: SILO

The authoring tool the students used to create the games is called SILO. Originally SILO was designed for Nokia, using Python for S60, which is the version the students in this study used. Currently it is being redeveloped for iOS and Android, and a first basic but working version became available in 2014. SILO has previously been described in detail elsewhere (see Wake & Baggetun, 2009; Wake, Guribye & Wasson, 2011; Wake & Wasson, 2011; Guribye, Wake & Wasson, 2014), so only a summary of the basic functionality is provided here for readability of this text: (1) SILO consists of a web-based game authoring tool and an app on the phone for playing the games. (2) SILO permits a game designer to construct a storyline as a set of missions, and attach the different missions to different locations, by clicking on a map, displayed on the screen. (3) The game creator can add icons to locations, set limitations on time, configure user data, and a maximum of three hints on how to find each location.

The phone application interprets the data, and converts it into a game to be displayed on the phone and lets the user interact using the following elements on the phone screen: (1) A scrollable map, an optional marker displaying one's current position on the map, an optional track displaying the history of movement, and a game score. (2) A distance meter (shown in red and green numbers), displaying the remaining distance to the next location, which is updated every five seconds. When a player moves within a zone of 30 meters around the location, the red numbers turn green, and they are permitted to 'pick up' the POI in the game. (3) A progress bar displaying the icons representing the places that the participant has visited, and a number of empty spaces, indicating game progress. (4) A menu system, to access the game score and "pick up" the available POI in the game. (5) A mission (i.e. a description of the next location from the storyline).

While the game is being played the application is constantly calculating the distance to the next location. The distance is displayed in red until the players near the location and it turns green indicating they can pick-up the location. They are then offered information about the current location and a text that describes the next location. The game then pauses, to allow the group to think about what to do next, and an icon signalling that they have picked up the previous location is displayed. The game is over when the last mission is solved (i.e. the last location is found).

Research methods

The research presented here is an ethnographic study inspired by ethnomethodology and conversation analysis, especially studies where the use of technological resources features as a central component in the analysis (e.g., Heath & Luff, 2000; Suchman, 2007). A key feature in these studies is the use of video recordings in the analysis (Heath, Hindmarsh & Luff, 2010). Video-based research has gained momentum in CSCL and the learning sciences (for an overview see Derry et al., 2010). As Koschmann, Stahl and Zemel (2006), point out, a key analytical commitment in such studies is "to discover within the recorded materials what the members are actually accomplishing (...) and are making relevant (...) through their interaction" (Koschmann, Stahl & Zemel, 2006, p. 7). The same analytical commitment guides the following analysis.

The main data source for this study was video, and the recordings form the basis for the analysis in this paper. A total of six sessions were filmed. These include the teacher's introduction, sessions which consisted of reading and re-writing source material tied to places, sessions where they created the game in the SILO interface, the session where they played their games, and the session where they created the media product. The recording of the activities resulted in a total of 12 hours and 45 minutes of video footage. One group was filmed for the whole scenario. The main researcher was present during the filming, and the recorded material was digitalised and reviewed after each session. To support the analysis, all the video has later been coded into a detailed activity log, describing the activities that occurred. Most sections of talk and interaction have been transcribed. Based on a review of all the transcripts, the ones that highlight the core activities involved in creating the games are presented for analysis in this text.

Additionally, interviews, observation and artefacts produced by the students were collected. Each student group was interviewed face-to-face two days after the scenario was completed. The groups that were not being filmed were observed while they worked, and field notes including which tools and sources they used, how they organised collaboratively, and so on, were recorded. The teacher was also interviewed in a more lengthy session, lasting about one hour. All interviews were recorded and transcribed. Furthermore, the student products that were collected included the games that they created and the media product that they created. The games were copied from the SILO system to a file in MS Word.

Analysis of the game design activity

In the analysis we focus on how designing games for *the others*-referring concretely to the group of students that will receive their game-features in their design process, how the group coordinate their collaborative work, and *how* the creative work of designing a location-based history game involves a series of design decisions. The excerpts are presented using the following structure, from left to right: turn number; turn taker: transcript of speech based on Jefferson transcript notation; and a description of other relevant aspects of the activity to the right. Original language is Norwegian, available below each translated utterance in grey text.

Excerpt 1 took place in the second session of the game design process, about an hour into the work session. Their interaction concerns how they coordinate their work in the group. They are seated around a table with one computer each, and writing the optional hints that will help players who are stuck during game play find the next location in the game. They are working with the list of themes provided for them by their teacher, and have not yet assigned all the themes to a physical location. In a previous exchange they have divided the themes between them.

Excerpt 1:

1	Hanna:	Which one should I tie it to then? (3.0) You wrote for number six there?	Picks up piece of paper with list of themes
2	Simen:	(0.7) >No for< (.) >no for< (.) for number three	Looks at the paper
3	Hanna:	(1.2) But we have to find out where to place it	Puts down paper

This excerpt is exemplifies how they interactionally coordinate their work, and in the process make explicit the kind of work they need to get done in order to finish their task. This kind of articulation work (Gerson & Star, 1986) is not a process that occurs separate from the content of their task as a kind of "meta-collaborative" interaction, but is inextricably tied to the content of their work. In Turn 1 when Hanna asks which theme she is to tie the hints that she has written to and whether Simen is already writing for theme number six, we see this mix in one utterance. It is a question of coordination and of how this ties to the actual decision she has to make about how to formulate the text and which location they have decided to have following the one she is writing about. In Turn 2 Simen specifies that he is writing for theme number three. Hanna then points out that they also need to place their text on a location on a map in SILO.

Excerpt 2 takes place in the third session of game design. The students are discussing how to connect the historical material with the narrative in the game.

Excerpt 2:

1 Hanna: Is that place to be mentioned in that hint sort of? Sitting next to each other

```
2
    Kaya:
             (.) I'm writing it like this (.) find the place
             where the Germans' ships were (inaudible)
             (2.0) Yes (.) But they don't know anything about
3
    Hanna:
             that?
4
    Kaya:
             (.) No
             (.) But they are going to learn it right? I feel
5
    Hanna:
             that it is a little
6
    Kaya:
             (.) Is that a little difficult?
             (.) Yes, because they have no relation to (.)
7
    Hanna:
             (inaudible) Yes it is actually possible to imagine
             of course
```

In Turn 1 Hanna asks whether she should include the name of the location about which she is writing, and in Turn 2 Kaya replies with giving an example of how she has written the text for one of her locations. The theme that she is writing about is the attack on Bergen on April 9th, 1940, and her choice is that the participants are to search for where the German ships were moored. In Turn 3, Hanna points out that the participants won't necessarily know where that is, to which Kaya agrees. In Turn 5 Hanna speculates that the participants are going to learn that, possibly through playing the game. She begins on a sentence where she assesses the difficulty in finding the location by the information they have made available. In Turn 6 Kaya finishes her statement by asking whether that is too difficult to understand. Hanna agrees that it is difficult, but not impossible if they use their imagination. In Turns 3, 5 and 7 in this extract the pronoun "they" is used. The use of *they* refers to the group that will play the game, and features throughout the interaction in this phase of the activity. In particular we see it in utterances such as the ones presented here, where it is a mix of envisioning what it will be like to actually play the game, and how difficult it will be to find the different points of interest, as articulated in Turn 6. This way they are explicitly bringing the other team (as players of a game) into their design decisions.

Excerpt 3 took place during the first session of the scenario. They are discussing the game mechanics as it relates to the first item on the list of themes that the teacher has provided, which they are to transform into a location in their game. More concretely the group is discussing where in the order of the route of locations they are to place this particular location.

Excerpt 3:

1	Simen:	We can't put the number one first (.) because then they will (start on) it straight away	Is looking up from pc screen
2	Hanna:	(1.5) Surely we can have the number one first (.) why not?	Looks at pc screen
3	Simen:	(0.5) No (.) because then they will receive it straight away (.) they won't even have to (guess)	

In Turn 1 Simen comments that they shouldn't place the top item on the list first, and argues that doing so will permit the other team (the group receiving their game) to find this location without any effort. Concretely, this location is their own school building, which was requisitioned and occupied by Germans during WW2, and Simen is presuming that they will start the game play session there. In Turn 2, Hanna responds to this statement by stating the opposite of Simen, which is that they can indeed place the school building first, and then asks why not, which prompts Simen to explain further. In Turn 3 Simen responds that it would make the other team find the location straight away, because of the 30 meter circumference around the school, which they presumably start the gameplay from, and that they wouldn't have to search for the location (that they will start the game from within the 30 meter circumference). His response highlights the central game mechanic element that gameplay is about searching for locations based on limited information, and that by placing their own school first, they would contradict this aspect of the game in their design. This is an important aspect of the game design, and another group used Google Street View to study locations closely before deciding on exact location of the POI (to search for natural obstacles to the decided game route not visible on maps).

Excerpt 4 took place in the third session of game design. They are discussing how difficult the game should be. Previous to Turn 1, they have discussed that they think the game should be challenging enough for the players to have to use extra hints in places, but that the game should still be possible to complete.

Exc	erpt 4:		
1	Kaya:	Yes (.) <u>cou::ld</u> make it (.) But they (1.5) It is not supposed to be like they are not to be able to make it	
2	Hanna:	(.) ^o This one is very simple (.) If you think like that $^{ m o}$	Lowers voice, both lean into the screen
3	Kaya:	(0.5) Yes maybe a little simple?	

In Turn 1 Kaya agrees that the game should be challenging, but that they should not make the game impossible to complete or too difficult. In Turn 2 Hanna responds by talking about one concrete location in the game, which she finds very simple. She points to the screen, highlighting the game information she is talking about. She lowers her voice considerably, to avoid talking loudly about game information, and both lean closer to the screen, and their body language clearly shows that they are hiding something, and that it is a matter of secrecy. In Turn 3 Kaya agrees that the location to which Hanna is referring might be too easy to find.

The whispering illustrated in Excerpt 4, is prevalent in much of the interaction in this phase. Although the whispering is partially a result of the students being placed in the same room as the team they were designing games for, it is clear that they orient themselves toward not revealing what they are doing for the other team.

Discussion and summary

In the game design phase analysed above, we have looked at an activity where the students are involved in learning through design. This idea is not new and a key argument in constructionism was that having students engage in design activity could be a fruitful way to support learning (e.g. Papert, 1980; Resnick, Ocko & Papert, 1988; Resnick, 2012). This paper offers a detailed empirical analysis of what kind of interaction the students are involved in when learning through design. A key observation is that the students in this learning scenario, where there were groups of students designing games for each other, do engage creatively with the learning materials and the resources made available to them. They need to transform the materials and concrete locations into points of interest in the location-based game. Further, they relate to the historical materials and sources to create a game and thus have to make design decisions and reflect upon how the game will be received by the other team of students. Such considerations are visible in the interaction and a topic of discussion in the group activity. We have illustrated this point through showing how the students explicitly address this through the use of "they" in their interaction, and showing how they explicitly discuss what the other students will learn from playing the game they are designing and finding the right level of difficulty for the game-play. In this way, the other team features as putative users of the mobile game in the interaction when they are making design decisions. This resonates with Woolgars classic study "Configuring the user" (1992) where he looks at how "along with negotiations over who the user might be, comes a set of design (and other) activities which attempt to define and delimit the user's possible actions" (p. 61). In our analysis we see an example of how the users are present in the design decisions of the teams where considerations of how difficult the game play will be relates to how they define and delimit the users' scope of action. The point that they are making a game for other students also points to a pedagogical challenge for the students: They are accountable for making a game that is playable for the other team, and the other team will evaluate them when they play the game.

This discussion also pertains to how the scenario was set up to be a collaborative activity. They collaborate in different ways, and in the above analysis we have looked at the process of *collaborative design*. When the activity is organised as a collaborative design activity, the students must coordinate their decisions and articulate content of the narrative for each other within the group.

A key idea in designing the authoring tool (SILO) is that it should be easy to design location-based games, and the design activity is tied to the construction of a narrative and descriptive text that ties the content to the given location. Some of the intricacies of this process are to find interesting physical locations to say something about a theme, to support a suitable sequencing of the POIs, and another is to place the pin and deal with the circumference of the POI. The students deal with these aspects in their interaction and collaborative activity. More generally, the authoring tool is designed to support the process of designing location-based games, and the notion of meta-design as discussed by Fischer (2009), a way to involve end-users in design by "designing for designers" is relevant. In this study we have showed a way to use an authoring tool for location based games to make students designers of games and in this way get them involved in learning through design and to be creative participants in what Fischer calls "richer ecologies of participation" and not only as passive

receivers of texts and other curricular materials. This strategy is also called *underdesign* (Fisher, 2009) and involves making tools for content creation rather than ready made content to be passively consumed, and creating technological and pedagogical conditions for participation in design activities. We see this as a promising way forward to support collaborative learning with technology.

This paper has presented a scenario involving the design of location-based games, where the participants' peers were to receive and play the game designed. Based on video focused on one group throughout the scenario, we have analysed their game design process. We studied how the notion of designing for their peers; *the others*, featured in their design process, how they coordinated their collaborative work, and how the creative work of designing a location-based history game involves a series of design decisions that have to be made.

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Science Through Technology Enhanced Play: Designing to Support Reflection Through Play and Embodiment

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Abstract: We describe the design of the Science through Technology Enhanced Play (STEP) project. In STEP, we explore the potential for dramatic play, a form of activity that is familiar to early elementary students, in promoting meaningful reflection about scientific content. We report on the first round of design experiments conducted with 18 second-grade students who explored states of matter within the STEP environment. Pre-post analyses indicate that the majority of students learned the content and demonstrate how the design promotes distinct forms of reflection. In particular, it appears that students attended to the projected simulation at key moments in play and then reflected on the underlying rules of the content.

Keywords: science education, technology, embodiment, elementary school, reflection

Introduction

In recent years, growing recognition of the role of embodiment in cognition coupled with the increasing availability of technologies that track bodily movement has led to a proliferation of instructional designs intended to support learning through embodiment (Lindgren & Johnson-Glenberg, 2013). These designs frequently rely on the mapping between specific bodily motions and related content, such as using a swinging arm gesture to reflect a pendulum (Segall, 2011 as cited in Lindgren & Johnson-Glenberg, 2013) or looking at data of one's own motion for mathematical trends (Lee & DuMont, 2010). However, focusing narrowly upon the alignment between an individuals' embodied activity and a concept in this way obscures how groups of students might interact to collectively embody more complex phenomena, and how the organization of activity may influence student learning. To address these contexts, we build upon sociocultural theories of learning (John-Steiner & Mahn, 1996) which highlight the importance of the sociocultural context in individual learning and cognition, and thus suggest that there is value in moving beyond embodied actions to examine how the organization of activity impacts the value that students glean from their actions. To demonstrate the value of this approach, we describe the design of the Science through Technology Enhanced Play (STEP) project, which builds on our previous work with the Learning Physics through Play (LPP) environment. STEP explores the potential for dramatic play, a form of activity that is familiar to early elementary students, in promoting meaningful reflection about scientific content. To illustrate this process, we also report on the first round of design experiments conducted with 18 second-graders using STEP to explore states of matter.

Background and design approach

Our design work is premised on sociocultural theory which suggests that all new knowledge is encountered first in social interaction before being "appropriated" by an individual (John-Steiner & Mahn, 1996). The notion of appropriation encapsulates the idea that learners' understanding of new concepts is shaped by their perception of how the new concept is used within a rich social context in addition to their prior experiences with similar concepts. While all social contexts can lead to learning, play is a particularly powerful space for early elementary students (Vygotsky, 1978). From a sociocultural perspective, the defining characteristic of play is that it always includes an imaginary situation and a set of rules (Vygotsky, 1978). The imaginary situation creates a context in which children can explore the rules in ways that were not previously accessible to them, allowing play to function as informal inquiry (Youngquist & Pataray-Ching, 2004). In fact, children often spend more time articulating and negotiating the rules of a play situation than actually "playing" their parts (Cooper, 2009). In this way, play is a social and collaborative activity that supports and encourages reflection.

Dewey (1933) defined reflection as "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it extends" (p. 91). More recently, Davis (2003) suggested that reflection can focus on several general subjects: on students' specific actions, on the activities or tasks in which they are engaged, on the content being studied, or

on students' knowledge in general. In other words, reflection is an opportunity for multiple kinds of sense making within activity. Our design work within the STEP environment is premised on the assumption that these multiple forms of reflection, which are promoted through play and can be seen both in students' interactions and teacher-led discussions, are central to the process through which students can explore new concepts. In our previous work with the Learning Physics through Play (LPP) environment (Enyedy, Danish, Delacruz, & Kumar, 2012; Enyedy, Danish, & DeLiema, in press), we demonstrated that play-based mixed reality environments are able to support early elementary students in reflecting on the rules of Newtonian physics, affording them an opportunity to explore concepts that are typically considered too challenging.

The STEP environment also uses mixed reality tools to combine students' embodied play activities with the power of computer simulations and thus support them in reflecting on scientific content. Mixed reality environments use software to combine elements of the real world with virtual objects and capabilities. In the STEP environment, students move around in the classroom space, play-acting how they believe water would behave in a range of circumstances such as a freezing cold day. They can see their activity projected into a computer simulation where an avatar of a water particle is displayed over the video display (see Figure 1). This avatar not only supports playful activity as a costume might, but also includes a representation of important information necessary for the students' inquiry such as the temperature in the imagined space or the energy level of the individual particles. The information represented is intended to direct students' attention towards key aspects of the content being studied. As the students role-play in the STEP environment, they make choices about how real particles might behave, and those choices are reflected within the projected simulation.

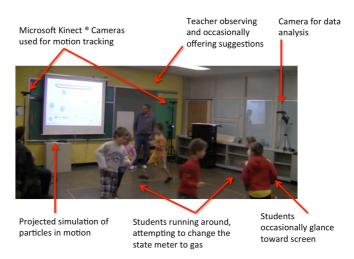


Figure 1. The STEP classroom environment

Thus, STEP helps to create a participatory simulation (Colella, 2000; Wilensky & Stroup, 1999) or participatory model (Danish & Saleh, 2011; Enyedy et al., 2012), where students work with peers to explore how their individual behaviors as particles of water influence the current state of the simulated matter. As the students collectively reflect through talk upon the nature of their shared model, they refine their understanding of the content. The STEP environment moves beyond our prior work by capitalizing on advances in computer vision to track multiple students without the need for physical markers, exploring a new content area (states of matter rather than Newtonian physics), and by more explicitly examining the role of play and embodiment in supporting students' reflection. In order to research the relationship between students' collective embodied play within the STEP environment and the kinds of reflection that it afforded, we designed a short 3-activity sequence intended to support students in learning about states of matter while engaging with the environment in several distinct ways. In particular, our goal was to help students to understand that matter is made of particles, and to begin exploring the relationship between energy, the motion of particles, and state change. We also wanted to target misconceptions such as the belief that the properties of particles are the same as the properties of the matter at a macroscopic level (Talanquer, 2009), and to overcome assumptions about particles changing or ceasing to exist at key points in state transitions such as when water boils.(Treagust et al., 2010).

Activity designs

We designed three sequential activities to begin exploring the potential of the STEP environment: 1) macrolevel costume play, 2) particle-embodiment play and 3) energy-embodiment play (see Table 1). While all activity is in some sense "embodied", our design focuses on promoting opportunities for groups of students to move throughout the classroom, using their positions and motions to shape the activity. We also aimed to promote dramatic play by encouraging students to take on a role within an imaginary situation and to explore their role somewhat freely. In costume play, students were first introduced to state change at the macroscopic level via the costumes that they selected. This activity was intended to introduce the technology, help students see dramatic play as a science activity, and to help them reflect on the relationship between temperature and changes in states of matter (e.g., heat causes ice to melt). In the particle-embodiment play, students play-acted as particles and explored how the space between each particle and its movement impacted the state of matter that was displayed on the screen (figure 2). In the energy-embodiment activity, students took on the role of energy sources (represented as small glowing balls), observing how energy impacted the behavior of simulated particle on the screen. In addition to allowing students to explore the role of energy in state change, we wanted to see how shifting from the perspective of being the object under study (the particle) to influencing that object would impact students' play and reflection. All of the activities required the students to discuss and coordinate their actions, and in the final two activities the teacher explicitly worked with the students to reflect on the "rules" that characterized their movement by recording these rules and revising them through their activity.

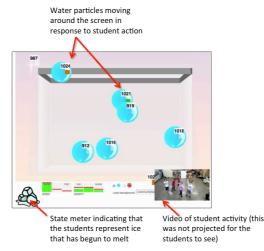


Figure 2. STEP software environment

Table	1:	The	three	play	<i>activities</i>

Play Activity Name and Description	Learning goals		
<i>Macro-level costume play</i> : Students selected characters and play-acted how they would move past an ice wall.	Introduction to macroscopic state changes.Introduction to causal relationship between temperature and state change.		
<i>Particle-embodiment play:</i> Students acted out how they felt particles of water might behave.	 Matter is made up of tiny particles, which are too small to see. Particles are always in motion. Motion and arrangement of particles affect state of matter. 		
<i>Energy-embodiment play</i> : The students acted out being sources of energy and attempted to change the state of matter.	 Temperature is related to heat energy which affects the motion of particles (e.g., higher temperature = higher energy) A change in energy is required for state changes to occur. 		

Methods

Participants and data sources

This study was implemented with 18 second-grade students (ages 7-8, 12 male, 6 female) at a public school in a small mid-western town. Students were divided into four groups. Each of the two participating teachers worked with a group of three students and a group of six students in a separate classroom where STEP was installed to explore the impact of group size upon our design. All groups participated in 3 activity sessions averaging 30 minutes per session.

Examining student learning

To examine student learning, we developed a pre-post structured interview, which included a range of questions about the nature of matter and how it changes state. We coded student responses using a scheme based on Paik, Kim, Cho, and Park (2004) to reveal the depth of student content understanding. Two sets of ordered codes (i.e., superficial to deep understanding) of matter (MT) and change of matter (CT) were established (see table 2).

Codes	Illustrative examples		
MT1: Observable characteristics of matter	It's just stacked up, ice is hard, water can just sinks down to the bottom but ice has to stack.		
MT2: Understand that matter is conserved	Really it's the same amount as this picture from that picture, cause it melts.		
MT3: Initial discussion of particles	The particles are frozen on a hot day it melts the particles can't handle		
(includes incorrect articulations)	that much coldness.		
MT4: Accurate discussion of particles (no	They [water] move a lot, medium fast, not like (makes whizzing-like		
incorrect articulations)	noise), that would be gas.		
CT1: Superficial description of state change	Water changes into ice.		
CT2: Some mechanism involved	It [The glass shaking] sorta rocks me around.		
CT3: Energy or temperature as mechanism	Energy made me [particle] move faster.		
CT4: Particle behavior as mechanism	Gas [particles] coming together a little bit more [to make liquid].		
CT5: Relates energy to particle behavior	Well, there has to be snow or something like that to get it cooler, and get		
and state change	the energy not flowing as much, so they [particles] move a little.		

Table 2: Summary of the matter-type and change-type codes

We conducted a chi-squared analysis to determine if there were a higher proportion of content codes from the pre interviews to the post interviews. To facilitate this analysis, each question was coded for either state changes (CT) or matter (MT), with the exception of one question, where both codes can occur. We then collapsed several codes into macro (MT1, MT2, CT1, CT2, CT3) and micro descriptions (MT3, MT4, CT4, CT5). The former represents students' observable properties and simple causal mechanisms of change of states, whereas the latter includes students' characterizations of particle behavior of matter and the relationship between energy, particles and state changes. We expected that students would articulate more micro-level descriptions than macro after the implementation.

Analyzing the design in action

In our analysis of the video data, we first sought to sub-divide students' activity into interactive sequences which manifest distinct normative structures and rules (Carspecken, 1996). We identified two general sequences in our data: classroom sequences and embodiment sequences. A classroom sequence is defined by teacherdirected activity, where instructions or discussions occur. An embodiment sequence differs from the classroom sequence in that it is predominantly characterized by play, 1) an imaginary situation and 2) rules that govern actions. These rules are instantiated when students take on different roles such as being a fire fairy, particles or energy and play-acting within that role. The software was also embedded with some rules regarding particle behavior, which shaped how students approached their roles. Embodiment sequences sometimes begin with a planning phase, where students discuss what they intend to do as part of their play, and may also narrate their actions as their play unfolds. Unlike a classroom sequence, both students and teacher are equally likely to begin or direct the sequence, observations made can be spontaneous, and students interact with each other and the screen, rather than with the teacher. All the videos were watched and categorized according to the two interactive sequences. These sequences were re-watched to identify specific sub-episodes within the sequences and to determine if there were patterns that emerged, particularly with reference to the type of reflection evident in students' talk and the accuracy of content talk that accompanied each sub-episode within a sequence. Episodes were coded in terms of the kinds of reflection that they included. To identify reflection, we modified the sub-categories suggested by Davis (2003) to better reflect our data and identified three types: 1) on actions (discussions of what students just did or what they will do next); 2) activities (broader activities that are defined by the design, such as being particles, being energy), and 3) reflection on content knowledge.

Results

Learning gains

After engaging with the STEP activity, students were able to articulate accurate descriptions of particle behavior in different states of matter, as well as the relationship between energy, particle behavior and state changes (see

Table 4). This included a significantly higher proportion of micro-level descriptions than macro-level descriptions after the implementation, X2 (3, N =524) = 142.18, p <.001 indicating that students generally provided more robust and normative accounts for how matter changes after engaging in the STEP activities.

	Macro	Micro	Other	Don't Know
Pre	191 (73%)	20 (8%)	21 (8%)	29 (11%)
Post	90 (34%)	148 (56%)	10 (4%)	15 (6%)

Table 4: Proportion of codes from pre and post interviews

The role of the STEP activities in supporting reflection

General patterns in reflection

Across all of the 4 groups and all 3 days of activities, students' patterns of reflection were relatively consistent. Each group began with a classroom sequence before alternating between embodied sequences where students played with the STEP software and paused to debrief their experience in a new classroom sequence. The initial classroom sequence consisted primarily of reflecting on students' prior knowledge of the concept being studied that day in response to teacher prompts. In all of the embodiment sequences, students' reflections were focused primarily on their physical actions. Content-oriented reflections in this sequence typically occurred only when prompted by the teacher and included a shift in orientation in their play from rather fluid and chaotic to more structured and deliberate. Once prompted, students' replies did mirror the kinds of depth displayed during the classroom sequences. It is also during this phase that some of the students' non-normative beliefs about how particles behave were indicated as they called out predictions regarding how they expected their behavior to impact the simulation. In general, it appears that the students did notice interesting patterns of relations during the embodied play sequence, but required teacher support to articulate many of them.

During the debriefing classroom sequences, which occurred immediately after their embodied play, the students' shifted to focus on reflection of the actions they just completed in their play, and how those related to their prior knowledge. In these cases, the students' reflections on their prior knowledge also became more specific, such as moving from discussing energy rather abstractly to discussing specific sources of energy and how they impacted the particles in motion and thus transformed the state of matter being displayed

Reflection during costume play

Students' reflection during the costume play activity largely focused on the stories that they were constructing with the costumes. They appeared confident in the fact that temperature leads to state change, and assumed that heat led ice to melt to water, and eventually led water to evaporate. The students were quite comfortable with the idea that an avatar would follow them around the screen and quickly focused on creating narratives together. Therefore, we will not describe this sequence in detail, as it seemed to primarily serve the role of introducing the students to the STEP software. However, one accidental event is worthy of note. In 3 of the 4 sessions, the teacher asked the students to create a play about how they would get through an ice wall. The students immediately focused on the avatars that represented the ice, or a heat source such as a fire sprite. However, one teacher inadvertently suggested they find a way "over" the ice wall. Those students shifted their attention to the animal sprites that would live in the frozen wasteland that was displayed (e.g., bears and deer) and explored how they might build a bridge over the ice wall rather than trying to go through it. Those students did not discuss heat and melting until it was re-introduced by the teacher. This unintentional contrast and its resulting shift in focus helps to underscore the relationship between rules and students' engagement with the content.

Reflection during particle play

During the particle play activity, each student was represented on-screen by a particle. The students could also see a "state meter" which depicted the overall state of matter based on their movement and relative positioning. For example, if the students all stood close to each other and relatively still, the state meter displayed a block of ice. In contrast, if the students were running rapidly around the space, the state meter displayed a gas. Once the students began to notice how their behavior influenced the state meter, the teacher asked them to embody a specific state. At these times the students would begin moving around, adjusting their movement as they noticed changes in the state meter (or the absence of expected changes). Students were quite playful and would often focus on their movement without looking at the screen. For example, when becoming a "gas" the students began running around as quickly as they could, some even beginning to play tag and try to catch each other.

However, students would sporadically notice their state either because one student would look up, or the teacher would draw their attention to it. At that point, they would attempt to adapt their movement, sometimes with one student taking on a "director" role and shouting instructions. These comments often focus on their actions and rarely included conceptual explanations unless the teacher prompted for them. For example, one group noticed that even though they were moving quickly the state meter still depicted a liquid. A student then suggested that they were too close together and needed to spread out. At this direction, the students stopped to spread out as far as the space would allow and then began running all in the same direction to attempt to create a gas. Thus, while students' talk during the activity appeared primarily focused on their specific actions, it appears likely that at least some of the students were reflecting upon the reason behind those actions. These details then became more explicit when the teacher asked the students to articulate their rules while debriefing.

While the rules were also articulated during debriefing sessions that occurred after the embodied play, one of our design goals was to help the students see their embodied play as a form of modeling where they could explore the content in greater detail, and notice concepts that were not previously apparent. This can best be illustrated with an example of students' exploring the question of whether molecules move when in a solid form. Students typically begin with the idea that particles only move in either liquid or gaseous states, but otherwise remain still in solid form. This is an example of an inheritance view (Talanquer, 2009), where students assume that properties of particles are equal to the observable properties of matter. This conceptualization of particles in solid state is a particularly challenging idea for students; only half of the students in the post interviews were able to articulate this accurately when asked demonstrate how the particles in solid ice behave.

The excerpt below demonstrates how the software and embodiment offers an effective way for students to better address their current conceptions. Prior to this, the facilitator had shown students a brief video about particles which depicted the particles in a solid as vibrating. Nonetheless, the students still suggested that particles within solid ice do not move. Excerpt 1 shows how the students worked with the teacher and the STEP environment to continue exploring this issue. First, we see that the students moved from their prior idea of modeling ice by hugging each other as closely as possible to recognize that a pattern (lattice) is necessary. On line 8, Adam shows the importance of the embodiment for articulating his idea by asking if he can physically demonstrate along with his peers. Initially, the students do not take note of the fact that they are still moving and in-fact they appear to be trying to hold as still as possible. However, the facilitator is then able to point (lines 12-16) how a little movement doesn't change the state meter from ice to water. The students then note, with the teacher's help, that a little movement is possible, an idea that they later re-articulate when drafting their rules about how particles behave when in solid form. One aspect of this example which is particularly compelling for us is that the students have previously watched a video of particles in solid form as a way of summarizing their earlier activity. Despite its clarity, the students persisted in their belief about ice particles remaining stationary. Fortunately, with the help of their teacher and the STEP environment, this group of students noticed that they could be stationary and yet exhibit movement.

Excerpt 1: Students embodying ice

1	Facilitator 1:	Do you remember the video when they showed us how the solids were arranged? Can anybody remember that in the video?
2	Adam:	They were like in a pattern.
3	Facilitator 1:	In a pattern. So when you guys were huddled together, was there a pattern when you
4	Students:	No
5	Facilitator 1:	No? So how do you think we should arrange ourselves?
6	Fred:	Oh I think we should arrange ourselves into a rectangle, or square.
7	Facilitator 1:	Do we want to try it out?
8	Adam:	Uh, how many people. There could be a line of three and like, another Can I demonstrate?
9	Teacher:	Sure.
10	Adam:	Can we stand up? Ian you can stay here. Stand in line with Ian, Mary. That's good [Students arrange themselves according to Adam's instructions].
11	Teacher:	What do we see on the screen? [Students form ice on the interface]
12	Facilitator 2:	So wiggle your fingers a little bit, and your toes. Are you still solid ice?
13	Students:	Yeah.
14	Teacher:	Well, that's movement.
15	Mary:	It's ba::rely movement.
16	Teacher:	Oh! Oh! Ba::rely movement

Reflection during energy play

During the energy play activity the students were represented on-screen as small suns that moved amongst a larger number of particles. If they stayed away from the particles, the particles eventually drew close together and slowed their movement, and then the state meter indicated that they had formed into ice. However, if they moved closer to the particles, the particles would slowly begin moving further and faster away, transitioning first into water and then into gas. This activity helped to highlight both the power of embodiment in our design, and the potential pitfalls to be avoided. Some students initially found the shift from particles to energy to be confusing, moving much as they had before; running around to be a gas and slowing to be a solid. However, they soon realized with the help of their teacher than they were in fact influencing the particles and thus played a different role in the environment. For example, see excerpt 2 below, which depicts the students in one group coming to understand this relationship after initially running around the space.

Excerpt 2: Students as energy

1	Facilitator 1:	Can you all line up on the back? I think that might help		
2	Students:	Yeah. [Students move towards the back of space.]		
3	Facilitator 1:	Alright, so now you can see the energy is moving out of the way. Now let's watch what happens to the particles.		
4	Carl:	The sun is moving away		
5	Facilitator 1:	So they're moving real fast right now, what do you think they are?		
6	Regan:	Liquid		
7	Carl:	Gas. [Students are far from the particles which slow and transition from gas to solid.]		
8	Neal:	Oh look, solid!		
9	Regan:	Solid!		
10	Facilitator 1:	There we go. Can someone describe, how do you know that's solid?		
11	Students:	Cause it's all together!		
12	Facilitator:	Ok, so now if we move the energy in so that you're starting to touch them, what do you think will happen? Step forward a little bit? [<i>Students step forward</i> .] Oh, so what's happening now?		
13	Neal:	They're coming apart.		

Some of the students in this group continued to find it difficult to reflect on the energy as separate from the movement of the particles. For example, when asked to "write down a note about energy" Neal suggested that "when energy moves freely, it usually means it's gas" whereas Regan noted that "whenever energy moves around, and it does not get in the way, of the gas or particles, then it … then it can come in and turn into solid". While the facilitator re-voiced Regan's idea, stating that "I think, what you're saying is that, if you stay out of the way so that there's no energy, the particles started to slow down and stay together and become a solid," it is clear from this that the students were attending quite intensely to their own embodied role within the activity, and that some found this confusing when their embodiment played an indirect role in modeling the system (e.g., as opposed to directly acting out the movement of the particles).

One of the more successful groups appears to have resolved this tension by electing an "observer" who directed the students-as-energy in their movement while attending to the state meter. This observer helped the students to recognize their role in influencing the simulated particles more clearly, and as a result they were able to articulate the role of energy in causing particles to move, and then tying that movement to the state of matter. Thus we can see that their embodied role within the simulation was important for both the students who were able to make this connection, and for those who struggled. Given how challenging students find this concept, we view this as a promising start and will incorporate the observer role into future design iterations in order to help students to transition between perspectives as they explore the simulated system through embodied play.

Summary and significance

The initial STEP implementation was quite successful, resulting in learning gains over the course of the three technologically enhanced play scenarios. By exploring students' reflections, we are able to focus on how the STEP activities and environment support their learning effectively, as well as moments where we can continue to refine our design. From our analysis, it is clear that embodied play was central to students' sense-making activity, and yet embodiment alone was not enough. Rather, the STEP environment supported this embodiment by providing key feedback to the students as they modeled the target system, helping them to see how their

movement, and the movement of their peers influenced the simulation. Furthermore, while the students appeared to notice many key principles through their embodied play, they didn't initially articulate all of these, and may not have even recognized them. Fortunately, with the help of the teacher and facilitator, the students were able to more clearly connect their observations and articulate the rules of the system. In sum, we believe the STEP environment helps to articulate how designs for embodied activity can benefit from moving beyond considerations of analogous movement (though that is still important) to include a focus on how play engaged students in reflecting on their movement, how software tools can help make the patterns in this movement more visible and relevant, and how teachers can help students to reflect more deeply upon the patterns they notice, and articulate the reasons for those patterns.

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Peer Scaffolding to Learn Science in Symmetrical Groups Collaborating Over Time

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Abstract: While educators often assume that students working together in symmetrical groups support each other's learning, this scaffolding may look very different from scaffolding in asymmetrical relationships. Little is known about *how* students in symmetrical groups support one another to learn. We examined scaffolding interactions of two symmetrical groups of students as they worked on physics simulations over time. We analyzed the interactions within each group to understand how students support their peers to learn science. We found that students in Group A had a significantly greater proportion of scaffolding discourse than students in Group B, but there were no significant differences in students' learning gains between the two groups. However, we found that one student in each group move forward with the task; this student made the most learning gains in each group.

Keywords: scaffolding, symmetrical peers, collaboration, science education

Introduction

Teachers cannot feasibly provide individual support to all of their students simultaneously in a classroom. One potential strategy to disperse the responsibility of instructing many students at the same time is to have students work together in small groups. Educators often assume that students in small groups will help each other learn (Webb, Baxter, Thompson, 1997); however, it is still unclear how support from peers affects students' learning. Can peers actually provide the necessary support to help each other learn? Evidence that peers can successfully support each other to learn together would further encourage utilizing small group work in the classroom.

Scaffolding describes the individualized support a teacher can provide to a student in order to help that student accomplish tasks that he or she would not be able to accomplish alone (Wood, Bruner, & Ross, 1976). This traditional notion of scaffolding involves an asymmetrical relationship between a student and a more capable other, often an adult teacher. Collaborative learning, however, refers to a group of students working together to learn or solve a problem; this usually involves a symmetrical group of peers who are often assumed to be of equal ability, prior knowledge, and status (Dillenbourg, 1999). While the symmetry of knowledge may shift between peers, the symmetry of status and participation is typically held constant. Scaffolding in symmetrical peer groups may therefore emerge as a mutual process in which different students scaffold at different times as symmetry of knowledge fluctuates (Sangin, Molinari, Nussli, & Dillenbourg, 2008).

Rogoff (1990) showed that there are interesting differences in the scaffolding that takes place within symmetrical versus asymmetrical relationships. We should not expect peer scaffolding to look the same as teacher-student scaffolding; the expert-novice relationship between a teacher and student is characterized by assessing the student's understanding and ability so that support can be specifically tailored to the unique needs of the student, whereas peers may not be able to assess others' needs and subsequently provide support in the same way (Rogoff, 1990). Research shows that scaffolding among equally inexperienced peers may be less explicit and intentional than teacher scaffolding, but still results in the group of peers being able to solve complex problems and complete tasks together that they could not do alone (Wells, 1999; Zuckerman, 2003). With the exception of a few examples, such as reciprocal teaching (Palinscar & Brown, 1984) and thinking together (Dawes, Mercer, & Wegerif, 2000), in which students are trained to give specific kinds of support and teachers intentionally model what scaffolding should look like in a specific context, students working in collaborative groups are usually not trained to scaffold in such an intentional way.

It is important to examine group discourse to understand whether peers play a supportive role and help each other learn. Research in computer supported collaborative learning has shown that groups who acknowledge, discuss, and build upon each other's proposals learn more than groups who ignore or reject proposals without discussion (e.g., Barron, 2003; Roschelle, 1992). Drawing from the traditional notion of scaffolding (Wood, Bruner, & Ross, 1976; Puntambekar & Kolodner, 2005), discourse including prompting peers, checking in to establish common goals and assess understanding, explaining concepts, and responding to others' questions would be indicative of quality group collaboration, which would benefit peers' learning. Thus,

we approach the investigation of small group collaboration from a peer scaffolding perspective, and we hypothesize that groups of students who exhibit these types of discourse would learn more than groups of students who do not engage in these scaffolding interactions. The reciprocal nature of interactions is a key aspect of scaffolding, so it is also important to understand how individuals contribute to the group's discourse.

In the current study, we take a more in depth look into the scaffolding interactions that unfolded in two groups of 6^{th} grade students with similar initial levels of prior knowledge working together on virtual physics simulations over a 12-week period. We aim to answer the question: How do symmetrical peers, working together in small groups, provide the support necessary to help each other learn science? To address this question, we first examined students' discourse to determine the types of interactions indicative of scaffolding among peers and how individuals contribute to these interactions. We also analyzed how these scaffolding interactions might relate to students' learning.

Methods

Participants and instructional context

We examined two groups (Group A and Group B) of four 6th grade students in their science classroom as they worked together during a physics unit. The students attended a US Midwestern public school located in a midsized city. The two groups of students were from the same science class, with a total of 27 students, taught by a teacher with three years of experience implementing the CoMPASS curriculum used in this study. We chose these groups for analysis based on the similarities in individual students' initial scores within the groups on a pretest of physics knowledge, since comparable prior knowledge is an important characteristic of symmetrical peers. We focused on using prior knowledge to define peers as symmetrical given the availability of this data.

The unit was a 12-week design-based curriculum in which students learned the physics concepts of forces, motion, work, and energy through investigating how to design a roller coaster. This curriculum relied heavily on the students driving their own learning through conducting experiments and research in small groups, instead of the teacher being the predominant source of information. The groups had autonomy to make decisions about experiments related to four major sections of their roller coasters (the car lift, the initial drop, hills, and stopping the car), and the students worked together to draw conclusions from these experiments in order to understand the physics behind their roller coaster design. Each small group worked together on one computer to participate in a total of nine simulated experiments addressing the different sections of their roller coaster. The student-centered and inquiry-based nature of this curriculum provided a rich context to investigate how students support each other to learn because learning outcomes would largely relate to the learning that occurred during group work, as opposed to information students might learn directly from the teacher.

Data sources and analysis

Pre- and posttest measures

The students were given a physics content knowledge test before beginning the unit to assess their prior knowledge and again after completing the unit to assess their learning gains. The test consisted of 29 multiplechoice questions addressing the physics concepts and relationships that the roller coaster unit was designed to teach. Each correct answer earned one point and incorrect answers earned zero points. Content validity of the test was established by consulting with physics experts. Groups A and B were chosen as the participants of this study based on the similarities of their physics pretest scores; the students in Group A had individual scores of 16, 17, 18, and 19 and students in Group B had individual scores of 14, 15, 15, and 16. We thus concluded that the students within the groups were symmetrical in that they had similar levels of initial physics knowledge.

Analysis of group discourse

The discourse within Group A and Group B was analyzed in order to investigate whether interactions to support the group's learning took place. We selected four videos of each group conducting virtual simulation experiments over the course of the unit; we selected the first video from each of the four sections of the unit to ensure the groups were completing the same activities and to capture students' discourse over multiple weeks. One group member from Group B was absent for the car lift simulation, so the remaining three simulations were used for analysis, resulting in six videos in total, three for each group, occurring over a span of four weeks.

The videos were transcribed, and we segmented the transcripts into lines based on turns of talk. We first qualitatively characterized the interactions among students in the two groups from the videos. We then quantified these interactions by coding each turn of talk for both the "content of talk" (what students were talking about) and the "role of talk" (what contribution the statements were making to the group). Descriptions and examples of codes are shown in Table 1.

The "content of talk" codes were developed based on our observations of what students talked about, including: a) science, b) metacognitive, c) procedural, d) off task, and e) not applicable content. We identified the codes of science and metacognitive talk (italicized in Table 1) as being beneficial interactions for learning, since students would need to engage in science related and reflective talk to develop conceptual understanding.

The "role of talk" codes were first developed based on the theories of learning through scaffolding discussed previously, including (italicized in Table 1): i) prompting collaboration for knowledge building, ii) checking in, iii) explaining, and iv) responding. Additional codes were later developed based on our observations of the data in order to further characterize the interactions among students, including: v) seeking help, vi) managing, vii) arguing, viii) reporting, and ix) not applicable role.

Each turn of talk could be assigned multiple codes. Since the context in which a turn of talk occurred was important in understanding the content of and type of talk that occurred, the discourse occurring before and after a particular turn of talk were taken into consideration in assigning codes. Inter-rater reliability was computed using Kappa; the first and second authors coded 15% of the transcripts, resulting in substantial agreement (Stemler, 2001) overall (K = 0.69) and on all but two individual codes—seeking help and responding. Discrepancies were resolved and the first author coded the remaining transcripts.

Code	Description	Examples
Content of talk:		
Science	Using science terms and / or discussing science concepts, definitions, and relationships	"If the height of the car increases, the work, required, will increase"
Metacognitive	Reflective statements that show a higher level of thinking or awareness about what is happening	"Okay, can we re-do trial 4? 'Cause I feel like my data was un-accurate."
Procedural	Discussing how to accomplish tasks or making decisions about simulations without discussing science content	"Well we have to write this down. Wait we need to record the beginning."
Off task	Discussing topics unrelated to science or the simulation	"No I think we need more flutes and clarinets and less trumpets"
Not applicable content	It is unclear what students are talking about	"So basically, so," (unintelligible)
Role of talk:		
Prompting collaboration	Seeking involvement of others; posing questions / statements to prompt group to work together to build knowledge	"So what are we gonna make the applied force, guys?"
Checking in	Inquiring if others understand the task and current plan or asking others to repeat something.	"Does everyone agree on that? "
Explaining	Describing science concepts or relationships to other group members.	"Like, as the height increases so does the distance. In order to keep it at the same angle."
Responding	Answering questions posed by other group members.	"Yeah I had to raise the increments too
Seeking help	Explicitly asking others for help and explanation, or stating confusion.	"What do you write? I don't know what this means."
Managing	Giving orders, telling others what to do, bringing others back to focus	"Write it down quick! Write it down quick quick quick!"
Arguing	Bickering, argumentative, rude, or confrontational talk.	"You're a control freak."
Reporting	Providing surface observations or interpretations of data, opinions without justification and/or support for predictions.	"Acceleration is 9.15."
Not applicable role	Unfinished or unclear statements, filler speech, off task talk not considered to be arguing, or repeating others' statements.	"Yeah," "Okay," (unintelligible)

Table 1: Coding categories for examining student interactions during simulations

Average interrater reliability: K = .69. Italics denote codes related to scaffolding and beneficial peer interactions for learning.

Findings

Quantitative analysis of differences in discourse between group A and group B

To examine the nature of interactions in the two groups, we quantitatively analyzed the overall discourse by the total proportion of talk in each category. We divided the frequency (shown in parentheses in Table 2) of each type of talk over all three simulations by the total turns of talk for each group. We then conducted a test of homogeneity of proportions comparing the total proportions of talk in each category across all three simulations, as shown in Table 2, to evaluate whether there were statistical differences in the discourse present between Group A and Group B. We were specifically interested in whether the students in Group A exhibited more

discourse related to scaffolding and beneficial interactions for learning science than Group B and whether Group B exhibited more off task and arguing discourse than Group A. We compared the two groups on all 14 categories and thus used the Bonferroni correction resulting in an alpha of .0036 for each comparison.

	Type of talk	Group A	Group B	Z score
Content of talk	Science	0.04 (28)	0.00 (3)	4.67*
	Metacognitive	0.02 (15)	0.00(1)	3.58*
	Procedural	0.59 (463)	0.49 (427)	4.22*
	Off task	0.11 (85)	0.33 (289)	-11.43*
	Not applicable content	0.21 (164)	0.18 (161)	1.30
Role of talk	Prompting collaboration	0.07 (54)	0.02 (18)	4.72*
	Checking in	0.12 (98)	0.10 (90)	1.42
	Explaining	0.02 (19)	0.01 (8)	2.37
	Responding	0.10 (77)	0.05 (45)	3.61*
	Seeking help	0.01 (6)	0.01 (9)	-0.57
	Managing	0.13 (102)	0.16 (140)	-1.72
	Arguing	0.03 (22)	0.11 (95)	-6.67*
	Reporting	0.21 (162)	0.13 (114)	4.12*
	Not applicable role	0.34 (268)	0.48 (423)	-5.90*

Table 2: Proportions (and frequencies) of talk across all three simulations and between group comparisons.

Italics denote types of talk we associate with scaffolding and beneficial interactions for learning. * p < .0036, significance level based on the Bonferroni correction for multiple comparison.

Group A showed significantly more science and metacognitive talk (both of which we associate to be beneficial for learning science) and significantly more scaffolding related talk of prompting collaboration and responding. Group A additionally showed significantly more procedural talk and reporting than Group B. In contrast, Group B showed significantly more off task talk and arguing.

Individual contributions to group's scaffolding discourse

To better understand the interactions indicative of scaffolding among peers, we took a more in depth look at individual students' discourse. Taking an individual perspective on each student's contribution to the group discourse allowed us to see the role each student played in the scaffolding interactions. We looked at the total frequency that individual students in Group A (Ravi, Anna, Owen, and Violet) and Group B (Henry, Ron, Silverio, and Max) engaged in each type of talk. Figure 1 shows the number of times individual students in Group A exhibited each type of talk. Most noticeably, Ravi contributed the most to Group A and engaged in the most prompting collaboration, checking in, and responding - all indicative of helping collaboration among group members. He also engaged in the most procedural talk and reporting so the group could complete their task.

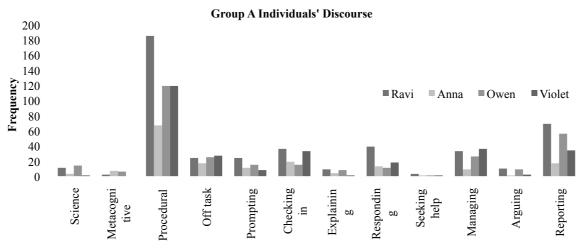
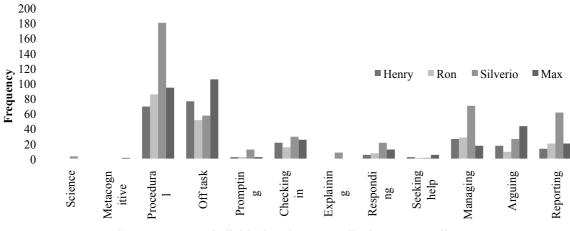


Figure 1. Group A individual students' contribution to group discourse

Figure 2 shows the number of times individual students in Group B exhibited each type of talk. Silverio contributed the most to Group B's discourse and exhibited most incidents of prompting collaboration, explaining, and responding, which are again indicative of helping group collaboration. He also engaged in the most procedural talk, managing, and reporting in order to move the group towards completing their experiments.



Group B Individuals' Discourse

Figure 2. Group B individual students' contribution to group discourse

We also summed each student's total frequency of talk related to scaffolding and beneficial interactions for learning (the codes italicized in Table 2) and divided by the total number of scaffolding and learning discourse of the group. This analysis revealed that Ravi emerged as having the highest proportion of talk beneficial and supportive to learning in Group A at 0.42, compared to Anna at 0.20, Owen at 0.24, and Violet at 0.21. In Group B, Silverio had the highest proportion of this talk at 0.44, compared to Henry at 0.17, Ron at 0.15, and Max at 0.24. These findings show that Ravi (Group A) and Silverio (Group B) were the predominant scaffolders in their respective groups. It is important to note here that while both groups had more capable students emerge as the dominant scaffolders, these more capable students had quite different styles of interacting with their peers. We conducted a test of homogeneity of proportions to compare Ravi and Silverio's talk. We found that Ravi engaged in a significantly more science talk, z = 2.24, p < .05; promoting collaboration, z = 2.22, p < .05; and responding z = 2.67, p < .01; than Silverio. We also found that Silverio engaged in a significantly more science talk, z = -3.87, p < .01; and arguing, z = -2.65, p < .01, than Ravi.

Qualitative description of peer interactions in group A and group B

To further exhibit the differences between the groups' discourse and interactions reported above, we identified examples typical of each groups' talk and provided a qualitative description to further illustrate the peer interactions in Group A and Group B. In Group A, all of the students generally worked together to solve problems during all three simulations. They stayed focused on the simulation experiments, discussed science concepts and relationships, prompted one another to collaborate, explained science concepts and relationships, and responded to each other's questions. Ravi more frequently attempted to scaffold his peers than other group members did, and he drove the group's discourse towards a conceptual focus by prompting his peers to work together to understand what was happening in their simulation experiments.

The following transcript excerpt shows an example of how the students in Group A were engaged in trying to understand science concepts and relationships during the virtual simulation experiments, worked together in a collaborative and non-argumentative manner, and checked in with and responded to one another.

- Anna I wanna like not the lift. I just wanna see, I wanna see like how fast it'll go if it does add friction because I'm just extremely curious. Ohh okay.
 Ravi Whoa the last, this, okay. Can we run the last trial again? With no friction,
- 2: Ravi Whoa the last, this, okay. Can we run the last trial again? With no friction, and, what, that's freaky.
- 3: Ravi Okay, can we re-do trial 4? 'Cause I feel like my data was un-accurate. Okay look at this though. As it goes up .2, this one's around 2. This one's .8, it goes up .8. Now this one is around 3 and 4, it went up 6. And this one, went up, this

is about .4, it went up 5...

4: Anna	Want me to play it?
5: Violet	Well I'm just gonna keep it in case
6: Ravi	It's inaccurate.
7: Anna	Guys can I?
8: Violet	Sure.
9: Anna	Kay it's, uh oh, sorry. The last three, 3.96.
10: Ravi	Okay, put um, the lift height maximum, oh you can just. And put like, half
	friction.
11: Anna	Oh wait, the initial drop correct?
12: Ravi	Uh huh, yeah.
13: Anna	Okay and I don't think that it'll work. 'Cause I tried
14: Ravi	No still?
15: Anna	See, it, it stops, but maybe if we add the uh, friction to the cart
16: Ravi	Oh my god. hahaha.
17: Anna	It'll just stop. I wonder what would happen if-

This excerpt shows an example of how Ravi guided the group, specifically in lines 2 and 3, to think about the physics relationships the group is experimenting with in the simulations and engaged in metacognitive talk (lines 3 and 6). This example also shows Anna and Ravi collaborating and responding to one another to better understand what was happening in their simulation.

In contrast, Group B's interactions were less productive overall and more focused on completing assignments. These students were frequently off task, argued with each other, and rarely attempted to scaffold each other. Their discussions about the simulations were procedural and focused mainly on task completion, as opposed to trying to understand the physics. Silverio noticeably took charge and managed the group by telling others what to do, making sure they were recording answers, and doing most of the work for the group. While Silverio seemed to be the most engaged with the simulation experiments and to have the best understanding of what was happening, he rarely attempted to support his peers by prompting them to collaborate and explaining science ideas.

The transcript excerpt below shows Group B's focus on task completion instead of conceptual understanding; it also exemplifies Silverio's characteristic managing style as he repeatedly tells his peers to write the answers down.

1: Silverio	Okay guys, start getting this stuff down. 5.9
2: Ron	Where's my pencil?
3: Henry	The lord took it.
4: Silverio	Guys! Get this down or I'll just hit start and I wont
5: Ron	Wait! I don't know where my pencil went
6: Silverio	Quick quick quick!
7: Max	Write it down quick! Write it down quick quick quick!
8: Silverio	I'm gonna hit it.

Silverio was clearly not concerned if his peers understood the answers they were writing; he simply wanted them to "get this down" so he could move on and run the next simulation experiment. Additionally, Henry's comment in line 3 provided a glimpse into the typical irrelevant and off task comments that were repeatedly made by this group. A second excerpt from Group B (below) further shows the characteristic arguing and managing interactions of this group.

- 1: Ron The maximum acceleration... Guys we need the maximum acceleration.
- 2: Silverio It's right there. Meoow
- 3: Max What the heck. This makes no sense.
- 4: Silverio It makes ton of sense! What're you looking for? What're you looking for?
- 5: Max Move. Maximum acceleration ...
- 6: Silverio It's right there! I just pointed at it. For the fifth time I'm done pointing it out.
- 7: Max ((inaudible talking, grumbling)) Stop speaking Japanese!
- You stop speaking Japanese! 8: Silverio

In this excerpt, Max and Silverio both used argumentative and frustrated tones. Line 6 shows Silverio's unwillingness to help Max further, even though Max was still confused. This was a missed opportunity for Silverio and the other group members to provide support and help Max learn.

Analysis of learning gains

We initially hypothesized that groups of students who engaged in more talk related to scaffolding and in more science and metacognitive talk would learn more than students who engaged in less of these types of talk. Following our findings from quantitative analyses and qualitative observations of the interactions between peers in Group A and Group B, we thus hypothesized that Group A would have learned more than Group B over the course of the physics unit. It is important to remember that the students started with similar physics prior knowledge, so learning gains are not attributed to differences in prior knowledge.

To compare the learning gains between the students in Group A (N=4) to those in Group B (N=4), we conducted an independent samples Mann-Whitney U test. Learning gains were calculated by dividing each student's actual gain between the physics pre- and posttest by the total possible gains that each student could have made. Calculating learning gains in this way, based on percentages as opposed to raw score differences, presents students' learning in terms of the amount they could have learn. The results of the test were not significant, z = -1.16, p = .25. Thus, there was no significant difference in the learning gains made by students in Group A versus Group B, despite clear differences in their discourse during the unit.

Further examination of the individual students' learning gains (reported in Table 3) showed that Ravi (Group A) and Silverio (Group B) made the largest gains in their respective groups. Thus, while there was no significant difference in overall learning gains between the students in Group A and Group B, the student in each group who contributed the most to the scaffolding discourse learned more than his respective peers.

Group	Student	Pretest	Posttest	Learning gain
	Ravi	18	21	27.27%
А	Anna	19	19	0.00%
11	Owen	16	19	23.08%
	Violet	17	12	-41.67%
	Henry	14	17	20.00%
В	Ron	15	19	28.57%
Ц	Silverio	16	24	61.54%
	Max	15	17	14.29%

Table 3: Individual students' learning gains

Discussion and implications

Educators often utilize small group work with the assumption that students will support and help each other learn, alleviating the teacher's struggle to simultaneously address many individual students' issues (Webb et al., 1997). However, the interactions that occur in a group and the ways in which peers support each other are different from teacher-student scaffolding. The goal of this paper was to better understand how students working together in symmetrical groups of peers support each other to learn. We specifically investigated 1) how the students in two different groups engaged in the types of talk we identified as related to scaffolding and beneficial to learning and 2) whether the presence of these types of talk related to students' learning over the course of the physics unit.

We found striking differences in how the students in our two groups interacted with each other. While Group A appeared to collaboratively work together and help their peers by prompting one another, responding to questions, and checking in with each other, Group B rarely appeared to support one another's learning. The students in Group A often focused on the physics content and discussed the science concepts and relationships behind the simulations, whereas the students in Group B frequently argued with each other and were often off task.

However, the most striking difference we found was that a more capable student emerged in both groups, contributing the most to and driving the discourse – but the ways in which this more capable student interacted with and supported their peers looked quite different. While the more capable student who emerged in Group A (Ravi) most frequently attempted to support his peers and guide the group towards understanding the physics concepts and relationships, the student who emerged in Group B (Silverio) frequently gave orders to his peers and was mainly concerned that the group completed the task at hand. Both Ravi and Silverio offered

support, but their support differed in line with their groups' overall discourse patterns with one student giving support for collaboration and conceptual understanding while the other gave support for completing tasks and staying focused.

Even though members in Group A worked collaboratively, their learning gains were not significantly greater than those of students in Group B. The findings in this study seem to contrast Barron's (2003) findings that the quality of group collaboration has important influences on student learning. Barron showed that groups in which students acknowledge, discuss, and build on others' ideas (similar to Group A) learn more than students who ignore or reject others' proposals (similar to Group B). However, what we found was that the student in both groups who acted as the "scaffolder" by driving the discourse and helping the group move forward with the task showed the most learning gains (see Table 3). This brings up interesting issues about how we can help group members support each other and about the interactions between the more capable peer and other group members. Despite the potential of having a more capable peer in small a group to support other group members, our results show that students may lack the intention (Wells, 1999; Zuckerman, 2003) or ability (Rogoff, 1990) to scaffold and help their peers learn. Students may rarely attempt to scaffold or support their peers, as seen in Group B, or students may not be able to provide the appropriate support needed to help their peers learn, as seen in Group A. In future work, we aim to better understand the interplay between scaffolding and collaboration, specifically helping group members support each other, in addition to providing them with guidance for better collaboration (e.g., Mercer & Littleton, 2007). We also aim to better understand the role that collaborative interactions play in learning and how the teacher might complement those interactions to foster learning of all group members.

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'Re-mediating' Learning

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Abstract: Building on our own and others' research about productive features of non-school learning environments, we describe a new experimental infrastructure for the organization and mediation of learning called FUSE. Activity in FUSE is mediated by a website and supported by an adult facilitator (typically a teacher, librarian, or other youth educator). Based on emerging research from the more than 4000 young people that have participated in FUSE in 30+ schools, libraries, and summer camps in the Chicago area, we have begun to characterize how the affordances of the FUSE website are supporting a shift in the material organization of learning in the in-school classrooms in which it is implemented. We describe how FUSE 'remediates' learning by providing individualized learning pathways, dynamic arrangements for learning, alternative forms of 'assessment', new roles for the teacher, and a rethinking of how curriculum materials are produced.

Keywords: technology, interest-driven learning, design, STEM, STEAM

Introduction

In this paper we describe a new experimental infrastructure (cf. Stevens, 2007) for the organization and mediation of learning. This infrastructure provides a coherent system of learning, 'teaching', and assessment that leaves behind the ways in which current education systems of teaching, testing, and curricula discourage interest, foster maladaptive motivational patterns (Dweck, 1986), and sort young people **out** of further academic pursuits (particularly more challenging scientific and technical fields – Seymour & Hewitt, 1997; Ames & Archer, 1988; Margolis & Fisher, 2002). First, we review some of the intrinsic challenges to transforming school-based learning practices with technology. We then describe how our new infrastructure, called FUSE, 're-mediates' learning by providing individualized learning pathways, alternative forms of 'assessment', new roles for the teacher, and a rethinking of how curriculum materials are produced.

Intrinsic barriers to transforming the organization of learning with technology

The material organization of learning in traditional Western schooling has remained largely unchanged, despite numerous attempts at reform (Becker, 1972; Varenne & McDermott, 1998; Cuban & Tyack, 1995). Technologies that have been introduced into classrooms have largely acted to reinforce rather than transform traditional structures and routines. A technology that is illustrative of the kind used widely in schools to maintain rather than transform the material organization of learning is the electronic whiteboard. Nominally intended to provide the teacher with an interactive computer display at the front of the room, this technology has for the most part simply provided teachers with an electronic method for displaying material to the whole class, replacing previous technologies of the overhead projector, chalkboard, and whiteboard. The electronic whiteboard changed neither the roles of teacher and student nor the organization of learning in the classroom.

Introducing technologies such as laptops and (more recently) tablets into schools has been heralded by both vendors and school leaders as a vehicle for transforming the traditional organization of classroom learning. Yet these technologies have largely failed to dislodge the teacher from directing learning from the front of the classroom; failed to break students free from lockstep progression through static curricula irrespective of actual learning outcomes; and, ultimately, failed to shift the initiative and ownership of learning from teacher to students. A promising exception are new blended learning models (Horn & Staker, 2014).

Collins & Halverson (2009, 2010) document the long history of innovative technologies that have failed to dislodge the industrial age structure of mass education. They identify a number of tensions between entrenched practices of schooling and the affordances provided by technology. These include:

• Uniform learning vs. customization. Current educational practices are based on a "mass production notion of uniform learning." These practices include sorting students into age-based (rather than expertise-based) levels and administering common assessments. Even though these assessments are based on a notion that all students should learn the same thing in the same period of time, the system

permits students to progress from one grade level to the next on the basis of only the most minimal mastery (i.e., anything but a failing grade allows one to move to the next class or grade).

- **Teacher as expert vs. diverse knowledge sources.** Despite widespread acknowledgement that we are now in an era of exploding knowledge production and instantaneous access, modern schooling is still largely based on the concept that knowledge is fixed and that a teacher's primary role is to present what is known to his or her students. This notion places teachers in the once-reasonable but now impractical position of all-knowing experts whose job is to pass on their expertise to students (who can now look up anything on their mobile phones faster than a teacher can respond).
- Standardized assessment vs. specialization. The high stakes assessments currently in dominant use require that every student learn the same things at the same time, yet technology now affords alternative forms of performance-based assessments such as video games and simulations (Hilton & Honey, 2011). Reputation-based measures of expertise grounded in communities of interest or practice are now typical in affinity groups including, for example, open source coding communities.

The traditional organization of classroom learning has been ossified and reinforced by layers of bureaucratic and administrative constraints. It is practically impossible for individual teachers to significantly change the material organization of learning in their classrooms, even if many secretly wish to and recognize how poorly the current system serves their students. Could a thoughtfully designed program, supported by technology, provide the requisite infrastructure to help teachers make a shift that many have long sought?

FUSE Studios

We are beginning to see evidence that such a shift is indeed possible. Building on our own and others' research about productive features of non-school learning environments (Bevan, Bell, Stevens, & Razfar, 2012; NRC, 2009; Barron, 2006; Stevens, 2000; Stevens, Satwicz, & McCarthy, 2008; Davis & Fox, 1999; Ito et al, 2013; Gee, 2007a, 2007b; Squire, 2003, 2011), we have created FUSE—a learning environment organized around a set of challenge sequences that 'level up' the way video games do. Some of our challenge sequences are software-based, including 3D design, digital music editing, app development, etc. For others that require physical materials, inexpensive, pre-packaged kits are provided (e.g., LEDs, breadboards, e-textiles, etc.).

The organization of learning in FUSE is mediated by the FUSE website and supported by an adult facilitator (typically a teacher, librarian, or other youth educator). Currently, more than 4000 young people have participated in FUSE Studios, exploring over 20 challenge sequences in 30+ schools, libraries, and summer camps in the Chicago area. Based on these experiences, we have begun to characterize how the affordances of the FUSE website are supporting a shift in the material organization of learning in those in-school classrooms in which it is implemented. (For an overview of FUSE, see http://www.fusestudio.net/program-design.)

Customization through choice

Youth participants have significant choice in FUSE Studios, a dramatic difference from their experiences in schooling. Participants choose whether to work alone or with others; they choose which challenge sequences they will explore; and they choose how long to work on a challenge sequence and when to move to another.



Figure 1. Left: An in-school FUSE Studio (color boxes indicate which challenges are being pursued); Right: Challenge popularity across the school year (each row is a different challenge, darker color and larger size indicate more participants).

Figures 1 & 2 depict the various arrangements and groupings for learning that emerge organically within a typical in-school FUSE Studio. Upon entering the room, students log on to their account on the FUSE

website and select a challenge to work on - either continuing a previously started challenge or starting a new one. Often the teacher need say nothing to his or her students - they immediately transition to productive engagement.

In order to provide an interest-driven, free choice infrastructure for learning, by definition there must be a wide range of challenges available for participants to choose from (see Figure 1 right, and Figure 2). The website scaffolds participant engagement and provides a participant's first layer of support while engaged with a challenge. Each challenge in a sequence has its own resource page consisting of short "how to" videos with tips on getting started, and answers to the most frequently asked questions. Participants each have their own unique login, allowing the website to track their progression through different challenge sequences. Participants can upload files, pictures, videos, and other artifacts to their online account to "save" multiple iterations of their work-in-progress. Completing levels unlocks higher levels in the same challenge sequence; just like in video games, participants must finish level one before moving on to level two. To complete a challenge level they must upload a final "completion artifact" (the self-documentation of level completion is discussed further in the 'assessment' section below). Similar to a Facebook feed, our site provides information about which challenges peers are engaged in and allows for sharing of completion artifacts. Clicking on a fellow participant's name highlights their profile showing what other challenges they have completed and thus the areas with which they might be able to help another participant.

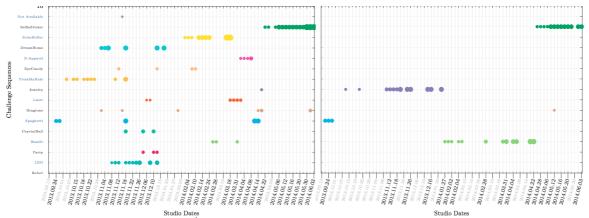


<u>Figure 2</u>. Examples of the diversity of material organizations for learning that occur in FUSE Studios. Participants dynamically arrange and rearrange collaborative groupings and individual activity with both material and online resources. Challenges illustrated here include (clockwise from upper left): *Dream Home*, *Laser Defender*, *LED Lights*, and *Selfie Sticker*.

The FUSE website structures and supports a participant-driven organization of learning. Each participant creates a customized rather than uniform learning experience by choosing the challenges that interest him or her, by working individually or with one or more peers, and by stopping and restarting challenge sequences at will. By indicating the leveling up progression for each challenge sequence, the website also provides clearly demarcated pathways to deepening expertise that each participant can choose to follow based on their own interest in doing so.

The FUSE web site logs participant activity and completed challenges allowing us to track which challenges participants are choosing and not choosing, and what levels they are completing or abandoning. From

this web data, we generate 'activity maps' (Figure 3, below). Our analysis of these activity maps has revealed a number of distinct patterns of participant engagement. For example, the participant whose activity is represented on the left in Figure 3 simultaneously worked on a variety of challenge sequences before pursuing Selfie Sticker exclusively (green dots, top right) at the end of the school year (the time period depicted in the map). In contrast, the participant whose activity is represented on the right in Figure 3 shows a much more focused pattern of engagement. This participant sticks with one challenge sequence at a time, generally pursuing that sequence through the final level. These are just two of a growing set of identifiable engagement patterns we are observing in the data. The design of FUSE, supported by the website, not only facilitates this diversity in the organization of learning, but also illustrates the significant variation in preferred approaches to learning that a thoughtfully designed and technology supported program can enable. These activity maps stand in stark contrast to the teacher-controlled, uniform pace and progression of lessons that is the hallmark of traditional schooling.



<u>Figure 3</u>. Activity maps from two 6^{th} grade participants in the same classroom across one school year. Each row lists a different challenge sequence (also represented with different color dots), while each column represents a date that the studio was in session. Larger dot size denotes leveling up to more difficult levels in each sequence.

Dynamic and flexible learning arrangements

Prior work (Stevens, Satwicz, & McCarthy, 2008) and our ongoing observations of FUSE have provided evidence that when youth participants are in the room together, they will be drawn to get involved with each other's challenge work. The differentiated levels of participation with particular challenge sequences that evolve naturally under this model over time multiply the possible sources of ideas, hints, help, and feedback in the room beyond those provided by teachers or other mentors. FUSE builds on Cole's (2009) work on the Fifth Dimension, a long-standing, successful after-school program, where peer-to-peer mentoring is ubiquitous. There, as in FUSE Studios, peers have differentiated experience; some are oldtimers and some are newcomers (cf. Lave & Wenger, 1991). This stands in stark juxtaposition to traditional schooling where everyone learns the same thing at the same time and pace.

The FUSE program design, with support from the FUSE website, enables more dynamic and flexible arrangements of participants in the room-arrangements which are mediated by the participants themselves and not the teacher (a few of these many arrangements are illustrated in Figures 1 & 2 above). One particular example in a 5th grade classroom highlights the nature of these arrangements and how they evolve organically based on differentiated experience and expertise. Our Solar Roller challenge sequence invites participants to build a solar-powered car that can travel a target distance with and without a light source using a provided kit of materials including gears, photovoltaic panels, capacitors, etc. When this challenge sequence was launched partway through the school year, it attracted the interest of many participants who wanted to try it. Unfortunately, because only one kit of materials was available in each classroom, participation was reduced to one "user" at a time. In one classroom, we observed several boys agreeing to collaborate as a group so they could all try it together (Figure 4). At first, all boys tried designing a vehicle independently, however, Arjun soon took leadership and combined the ideas into one vehicle. All of them suggested ideas for building the roller, and when testing time came, they each took ownership for different aspects of the testing. For example, John had a fancy watch and used it to track the roller's time to reach the goal distance, until they found a stopwatch and he started using it instead. Arjun seemed to have the most success with the light used to make the vehicle move, so he took that responsibility. Ian noticed the light cord kept getting stuck on the table, causing the light to stop powering their vehicle, so he took responsibility for keeping the cord clear of obstacles (see

Figure 4). As their design and testing progressed, they all found meaningful ways to contribute to the group. This group even pooled their money, purchased a similar kit of materials from another website, and brought it to school to use in additional experimentation and development that went beyond the challenge sequence on the FUSE website. This group worked on this challenge together multiple times over the course of three months. While there were five members of this group, not all members participated at all times; occasionally one and often all of them would take a break from this challenge to work on a different challenge.

This example highlights one of the many ways participants dynamically and flexibly positioned themselves in productive learning arrangements. This group worked cooperatively on their car design, while each boy filled a different role during testing that helped their team move efficiently towards their goal. These roles emerged dynamically as they worked together and developed expertise in different aspects of their vehicle testing. They themselves decided when to pursue this challenge and when to work on a different challenge sequence. Other arrangements of independent and collaborative work are shown in Figures 1 and 2.



Figure 4. A dynamic grouping of participants testing out their Solar Roller car.

Alternative forms of 'assessment'

Another difference from school is that FUSE participants are never graded and they self-document their completion of challenges, which unlocks subsequent challenge levels in a sequence. Our approach to assessment seeks to balance the need to recognize participants' achievements in a fair way (i.e. that they have been active participants in completing a challenge) with the concern of not wanting students to fall back into the learned helplessness with respect to self-assessment and achievement recognition that is so common in schooling (Dweck, 1986). We accomplish this using a combination of careful challenge design and a documentation and endorsement process.



Figure 5. Participants self-documenting success on a challenge (Just Bead It, left; Spaghetti Structures, right).

Our alternative to standardized assessment involves designing challenges that have a clear criterion of success: a light either goes on or it doesn't, a robot navigates to the finish line or not. We want a participant's success at achieving the challenge to be obvious both to the participant and to others in the room. Once a participant has succeeded at a challenge, they self-document their success by capturing and posting a photo or video of it on our site, or by uploading a digital artifact (3D design, mobile app code, etc.). The image on the

right in Figure 5 below shows a group of girls documenting their completion of a *Spaghetti Structures* challenge. What is especially striking is that they are in the picture with their artifact-an indication of pride and ownership in their work that is rarely seen when students complete a math worksheet.

By shifting the ownership of 'assessment' away from the teacher and to the participants themselves, we make a move toward investing participants in the quality of their own artifacts, towards a sense of pride of accomplishment. In fact, we have observed numerous occasions where participants have gone well beyond the requirements of completing a challenge and have become deeply invested in an artifact they are creating. One girl spent nearly 12 weeks refining the design of her earrings for the first level of the jewelry design challenge. She could have easily gone on to complete the remaining levels and numerous other challenge sequences in that time, but she chose instead to invest in producing something that met her own standards and personal goals.

Changing the role of the teacher

In FUSE, adults play a facilitative or coaching role, rather than delivering direct instruction and coordinating grading and assessment. This arrangement is driven by both theoretical and practical considerations. Practically speaking, the diversity of challenges makes it unreasonable to expect a teacher or other facilitator to be expert at such a broad range of topics, tools, and skill sets. We have found, however, that this realization has been liberating rather than intimidating for teachers. It seems that the very diversity of challenges has forced the recognition that *a priori* mastery of all challenges is impractical. Freed from the traditional role of being the all-knowing expert, teachers have embraced their new role in FUSE as a coach and fellow problem-solver. Participants often become more expert at certain challenges or technologies (e.g. the 3D printer) than the teacher. We have observed numerous examples of the teacher referring questions to one or more of the participants who have become recognized in the room for their deeper expertise.

Reconceptualizing production of 'curriculum'

Our approach to designing activities in the form of challenges and sequences is very different from traditional curricular design approaches (e.g., Wiggins & McTighe, 1998). The traditional approach begins with a set of disciplinary knowledge standards and then projects those standards into an organized set of curricular activities and formal assessment instruments and media; traditional curricula are built as standardized packages that are significantly monolithic, minimally revisable, expensive, and largely indifferent to individual student interests. Our design approach is fundamentally modular and evolutionary, in which challenges are dynamically created, positioned, revised, and discarded in relation to other challenges that precede them that have proven successful. The crucible of participant engagement, as measured by persistence in working to achieve challenges, has been and will remain central to our design approach. A similar logic organizes our approach to designing distinct sequences; we design new sequences if we find we are not engaging a segment of the youth population. For example, in response to a desire to better engage female participants, we introduced a jewelry design challenge using a 3D printer. This challenge sequence markedly increased the percentage of female participants engaging in 3D design challenges and remains among our most popular challenge sequences.

We use the data from our website to determine which challenges appear to be sticking points for participants. How they are sticking points cannot be determined from the analytics; we use the analytics data to guide us to where to look in our field data (i.e., video recordings) to determine how and why challenges are problematic. Challenges may be uninteresting, have instructions that are hard to follow, lack sufficient scaffolding, or increase the level of difficulty from prior challenges too quickly. We then revise challenges and sequences on the basis of what we find from field observations. For example, in our Robot Obstacle Course sequence, we saw a drop-off in engagement after level 2. In-room observations and interviews revealed that the introduction of a required sensor was too big a step between levels 2 and 3. In response, we inserted a new level 3 so participants could understand how the sensor worked before requiring them to integrate the sensor into a complex program (now moved to level 4). We regard this approach as a generative way to use a learning analytics perspective without falling into the naïve view that analytics data alone can provide meaningful and specific guidance for design iteration (Stevens, 2013). For that, we need to look 'beyond the interface' directly at participant activity. The design based research (Design-Based Research Collective, 2003) approach we employ is a significantly new one, in that iteration is rapid and informed in a very direct way by participant experiences; iterations are initiated not by tests of sequestered disciplinary knowledge but by evidence of ongoing, interest-driven participation and engagement in challenge sequences.

Conclusions

To instantiate FUSE as an alternative infrastructure for learning, and to do so in a scalable manner, requires that our website help mediate and structure participant activity and learning. This paper highlighted a number of specific functions served by the FUSE website in doing so:

- **Enabling personalized choices based on interests.** Participants use the website to explore available challenge sequences and to select those that interest them.
- **Providing pathways to deeper expertise.** Initial challenge levels are relatively easy, but increase in difficulty. The leveling up sequence is communicated by the website and provides participants with a clear indication of where they can go next if they choose.
- **Enabling dynamic arrangements for learning.** FUSE enables more dynamic and flexible arrangements of participants in the room—arrangements that are mediated by the participants themselves and not the teacher.
- **Redefining the role of the teacher.** By shifting the primary content expertise and scaffolding burden away from the teacher, the website transforms his or her role to that of facilitator and guide, allowing a focus on process coaching and nurturing peer learning interactions.
- **Documenting learning outcomes.** The website also shifts the 'assessment' burden away from the teacher and to the individual participants by having them upload evidence of their completed challenges.
- **Supporting peer collaboration.** By disseminating information about which challenges peers are currently working on or have already completed, the website facilitates a rich set of peer collaboration and helping behaviors.
- **Capturing user data to support iterative refinement of challenges.** Analyzing patterns of participant engagement with the set of FUSE challenges provides an important lens into which challenges are appealing, to whom, and which may need refinement.
- **Providing a research platform.** Finally, by mediating learning activity on the website, we are able to study young people's interest-driven learning, problem solving, and collaboration activity at scale and with a level of granularity that would not be otherwise possible.

These shifts in the material organization of learning in school are often initially intimidating to the teachers who facilitate FUSE in their classrooms. However, with time, teachers begin to embrace these shifts and, in interviews, have indicated that they are using some of these elements in their "regular" classes as well. One grade 7-8 science teacher commented:

Students enter the program with little to no background knowledge and quickly start developing skills in computer-aided design, electronics, and robotics. The enthusiasm students feel when they accomplish levels is contagious and because of the program's thoughtful design, students feel safe and secure with continuing to try new challenges that they previously thought too difficult. Students are instantly hooked and love progressing through the challenges, which are academically rigorous, but also insanely fun, exciting and teen-focused.

As we have highlighted here, the FUSE website is an essential element in the successful implementation of FUSE Studios. It provides both a tool for scaling up to a growing number of implementation sites as well as a research tool for studying learning in an interest-driven context. Most critically, the website demonstrates that technology, when thoughtfully designed and implemented, can in fact "re-mediate" learning in ways that productively transform rather than reinforce the practices of current education systems.

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Tarzan and Jane Share an iPad

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Abstract: Increasingly, tablets are entering children's lives and the classroom. We developed the Proportion iPad application to investigate how tablets can support at-device collaborative learning. We provide a microanalysis of a particularly successful dyad to concretely demonstrate our vision of at-tablet collaboration. We analyze the processes of strategy development, territoriality, modes of collaboration, emotion regulation and task focus.

Collaborative learning with tablets

Multi-touch devices are starting to replace PCs (both desktops and laptops) as the dominant form of computing, particularly for children. As a result, serious efforts are underway to investigate and integrate tablets into both the primary (Gasparini & Culén, 2013) and secondary (Kaganer et al., 2013) classroom. Most of these research efforts are software agnostic, assuming that the current software ecology is sufficient to realize and study the potential of the hardware. In such a research mode, it is natural to think of tablets as personal devices since the vast majority of software is built around that premise (e.g., tablets as ebooks). Can tablets support collaborative learning?

One approach is to have tablets act as personal devices (one user per tablet) but orchestrate activities through software to further collaboration. For instance, Group Scribbles utilizes a classroom projector as a large shared display that can be used to share objects across tablets (Roschelle et al., 2007). The SINQ tablet application allows children to keep and share notes on their inquiry activities; as the information is shared, it affords others noticing connections and spurs on face-to-face collaboration (Ahn et al., 2013). There is less work on using tablets as collaborative devices (multiple users per tablet). One notable exception is the work of Hourcade et al. (2013) on using at-tablet interaction to help children with ASD (Autism Spectrum Disorder) to become more comfortable working with one another; the joint tablet use encouraged a greater rate of verbal interactions than comparable non-electronic activities. Why would at-device collaboration be useful?

A seminal vision of how technology can support at-device collaborative learning is Roschelle's (1992) theory of *convergent conceptual change*: a process by which two novices working with a *reflective tool* help each other converge on a better domain understanding. Roschelle illustrates the process with two children working with a Newtonian motion simulation. The children were instructed to hypothesize solutions to problems and test them with the software. As both were novices, neither came in with the correct understanding; however, the two generated many ideas and were able to build on each other's successes and failures. Using the tool, they were able to test their hypotheses and reflect on the outcome. Over time, they converged on an understanding that was more closely aligned with each other and the underlying principles. While Roschelle used a desktop PC, interactive surfaces may be more suited for supporting this type of interaction. First, they may further more equitable interaction as no user can dominate the mouse. Second, they may enhance shared focus as large body movements are easier for partners to monitor than small cursor movements. Third, they may make it easier to switch from gesturing to communicate with a partner to gesturing to interact with the application. Already, there is an established research tradition of using interactive tabletops to support collaboration (Higgins et al., 2011) and learning (Dillenbourg & Evans, 2011; Evans & Rick, 2014).

Tablets as tiny tabletops

Interactive tabletops are commonly regarded as collaborative devices; in contrast, tablets are thought of as personal devices. While significantly smaller, tablets share two key properties of tabletops: direct input and multiple access points. *Direct input* means that an end user can directly manipulate the software interface using touch, pen and / or by moving tangible objects. In comparison to using a mouse to control a cursor, the cognitive distance between intent and execution is shortened. This benefit is particularly salient for younger users (e.g., toddlers using tablets). *Multiple access points* means that multiple concurrent interaction points are sensed by the hardware and utilized by the software. This enables both multi-point gestures, such as pinching with two fingers to zoom out, and switching which hand to use. In addition, the access points can be distributed among multiple participants, thereby enabling collaboration. Because of this common core, we hypothesize that collaborative learning can be similarly supported with tablets. We ground our tablet efforts in tabletop research.

We start with the premise of working with learners in the age range of 9-11. This has been a

particularly fruitful user group for tabletop research. In comparison to older children, they are more willing to experiment without fear of embarrassment and do not mind working in physical contact with their peers. They generally prefer working side-by-side (Scott et al., 2003). In contrast to younger children, they have a refined ability to work with peers (Harris et al., 2009). Though there are similarities in the two technologies, we expect display size to have an effect. Tabletops are large enough that children can work independently (Rick et al., 2011); however, interface conflict can be an impetus for learning (Pontual Falcão & Price, 2009). Tabletop applications tend to promote territoriality, where users take responsibility for the screen area near them (Scott et al., 2004). This may be partially attributed to reach as users cannot easily reach all parts of a large tabletop (Rick et al., 2009), which is not an issue for tablets. To investigate such differences and at-tablet collaboration in general, we developed the Proportion iPad application.

The Proportion app

Ratios and proportions play a critical role in students' mathematical development (Lamon, 1993). Because of its importance and depth, the topic is covered repeatedly and in increasing sophistication in several grade levels. *Proportional reasoning* is realized through multiple strategies, where one strategy will be appropriate for one set of problems but inappropriate for another set. For instance, in cases where the denominators are the same, the ratio of two fractions is the same as the ratio of the respective numerators; if the denominators are different, this strategy fails. Gaining competence requires both acquiring such strategies and understanding when and how to apply them (Tourniaire & Pulos, 1985). Proportional reasoning is notably difficult to teach (Lamon, 1993). Digital technologies can support this process by offering both immediate feedback and creating accessible embodiments of the mathematical concepts (Abrahamson & Trimic, 2011; Leong & Horn, 2011).

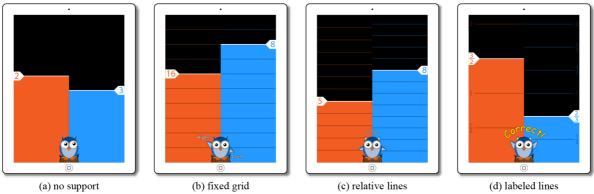


Figure 1. Four interfaces for supporting learners in solving problems

In Proportion, the tablet is positioned in portrait mode on a table in front of the learners. The children (aged 9–10) work together to solve a series of ratio / proportion problems. The interface features two column: a left orange and a right blue ones (Figure 1). For each problem, users must size the columns so that they are in proportion to their numerical labels. For instance, for the problem in Figure 1a, the blue column (3) must be resized to be 50% larger than the orange column (2). A touch or drag on a column changes its position. The application features a young owl at the bottom of the display to provide reflective feedback. The owl "watches" the children work, moving its eyes to the last touch location and peaking its ears when they talk. When all touches are released, the ratio of the column heights is evaluated. If it is correct (Figure 1d), the owl announces "Correct!" and hoots loudly; the next problem is presented. If the ratio is nearly correct (1c), the owl announces "Close" and hoots softly. If learners have been working for more than one minute on a problem, the owl provides directional feedback (1b); this allows learners to make progress without the help of a teacher.

Proportion has been refined through two cycles of user testing (Rick et al., 2012). Its curriculum contains 215 problems divided into 21 levels. Each level uses one of four interfaces (Figure 1). With no support (1a), learners must estimate the ratio. With a fixed 10-position grid (1b), learners have precise places that they can target, which, if correctly utilized, will allow them to quickly solve the problem. With relative lines that expand based on the position of the columns (1c), learners can use counting to help them solve the problem (e.g., when solving 5:8, students can count down three spaces from 8 to achieve 5). When the lines are labeled, it becomes even easier to line up the correct values. In the fraction example (1d), a useful strategy is arranging columns so that the whole numbers (e.g., 1) are at the same level. In addition to the numerical labels and the interface available, each problem has a specified tolerance level for what is accepted as close and what is accepted as correct. As a sequence progresses and children gain competence, more precision is demanded.

With its two columns, there is a natural symmetry to the interface that does not privilege a specific partner. Both have good access to the entire display and how they utilize it is up to them. A common strategy is that the partner on the left controls the left column and the partner on the right controls the right column. Such a strategy would utilize a concept of territoriality based on nearness, rather than comfort.

The case study

We conducted a field study of Proportion in local schools. For each session, we took half of a fourth grade class (10-12 participants per session) and randomly assign them into three conditions. In the *single-user condition*, a learner works alone with the iPad. In the *multiple-touch condition*, two children work together with a Proportion implementation that allows both columns to be resized simultaneously. In the *single-touch condition*, two children work together, but only one column can be resized at a time. This allows us to investigate the value of collaborative learning and multi-touch support. Each session takes 90 minutes. First, participants are randomly assigned to a group / condition. Next, they complete a short survey and pre-test. Then, they spend 40 minutes working with the iPad; their interaction is recorded on video. Finally, they complete a short survey and post-test.

While we aim to ultimately compare across conditions, we wanted to get a better sense of *successful* attablet collaboration. How do proportional reasoning strategies develop while children work together? How does the collaboration at the tablet differ from collaboration at the tabletop? In particular, how do children physically engage the tablet? What makes for a successful group? To address these questions, we concentrate on one remarkable group from this larger sample: Tarzan and Jane. A case study is a well established technique for analyzing novel forms of learning as an exemplary case can give a feel for what is possible and ground the abstract theory in a concrete instantiation. For example, Roschelle (1992) illustrates how two novices can benefit from collaborating with a reflective tool. Bruckman (2000) shows how mentoring relationships can work between children in an online forum.

To analyze the case, we four authors closely examined the video and screen capture of this dyad, noting important elements to capture the essential parts of the interaction. We have grouped our findings into three categories that seemed most salient. First, we describe how learners acquire and exercise proportional reasoning strategies. Second, we discuss the nature of the collaboration at the tablet, concentrating on body and tablet position, which differs significantly from the literature on tabletops. Third, we analyze task focus and emotional valence. We provide both qualitative (overall description and illustrative examples) and quantitative (descriptive statistics, coding) analysis. Before presenting our findings, we introduce the pair.

Tarzan and Jane

Tarzan and Jane are nine year olds in the same class; to aid the reader, we translate their German speech into English. We focus on them partly for convenience: Their loud voices are easily deciphered while other groups regularly mumble or whisper. They also stand out in key ways. First, their interaction features a lot of tablet movement and diverse body configurations, which contrast to the literature on stationary tabletops. This behavior is largely activated by the single-touch condition, where the common *territorial strategy* of "left user manipulates left column, right user manipulates right column" proves unsatisfactory. Second, they present an unusual, yet effective interaction pattern. Collaboration at interactive surfaces, as with other group work (Stahl, 2006), often depends strongly on the how learners regulate each other. Strikingly diverse dynamics can lead to useful collaboration (Rick et al., 2011). As our fanciful pseudonyms suggest, he is a bit unruly and she provides a calming influence. The teacher specifically warned us about Tarzan, noting that using an iPad and being filmed will overstimulate him. Third, they are a highly successful group. Of the seventeen dyads using Proportion at this school, they started off with the second lowest combined pre-test result. They also liked math class slightly less than the average. None of this suggested that they would be remarkable; however, they reached third furthest into the problem set of the groups (127 problems in 40 minutes) and had the highest posttest score by a wide margin. They were pleased with their collaboration, giving maximum marks to all questions on the post survey. Hence, they provide an excellent case of how a tablet can support at-device collaboration.

Learning new strategies

The Proportion problem sequence has been carefully designed to highlight various proportional reasoning strategies (Rick et al., 2012). By solving the problems, learners should discover and apply these strategies. While it is possible to make progress without a particular strategy, utilizing the appropriate strategy makes it significantly easier. As such, children can recognize that the strategy is a valuable one: It saves them time and effort. Accordingly, we focus on the appropriation of new strategies. Acquiring a strategy generally goes through three phases: *discovery, application* and *pertinence*. First, children try various strategies to solve the current problem. If one works, they might try it again. If it is a viable strategy, it works again. Thus, they

discover the strategy. Once it has been discovered, the next step is to apply it. Repeatedly practicing it demonstrates its utility. For this task, none of the strategies are universal; they all have their limitations. At some point, learners will face problems where that strategy does not work or where another strategy is significantly better. So, learners will have to figure out when that practiced strategy is pertinent to the problem. To demonstrate these phases, we detail how Tarzan and Jane engage with the maximum column strategy.

The *maximum column strategy* has users placing the column with the highest value to its maximum height. This is done so that it is easier to precisely place the smaller column. A prerequisite is understanding that there are multiple solutions for each ratio problem. Tarzan and Jane first glimpse the strategy while working on 3:2 with labeled lines. 3 is set fairly low (based on the last problem); although they know roughly where 2 needs to be placed, placing it correctly requires near pixel accuracy. Jane fails to place it just right. Tarzan says, "wait, wait, I'm going to set this one higher." He sets 3 to a higher position (though not to the maximum position) and they quickly place 2 to solve it. On the next problem, he again sets the higher number a bit higher to make the lower number easier to place. On the following problem, he first employs the (full) maximum column strategy. He repeats it on the next problem, verbalizing, "that one [column] to the top." He has discovered the strategy. As it works, he continues championing it, while it takes her a while to adopt it. At one time, he places a column to the top. When she accidentally brings it down, he proclaims "no, to the top" and corrects it. On the next problem (5:1), she adopts the strategy (placing 5 to the top). They continue applying the strategy. Both have now accepted it as a useful strategy. On one problem, Jane is working alone and employs it.

Next, a sequence of fixed grid problems arrive. For these, the maximum column strategy will be less useful. Instead a *counting strategy* (place each column at the grid line for the respective numerical labels) will displace it. At first, they continue to use the maximum column strategy. It does not work well. In particular, Tarzan does not realize how to utilize the fixed grid. He tries to use a combination maximum column and subtraction strategy. He places the column with the highest number at the top of the screen and then counts down one grid division for the difference in numbers. For 4:1, he places 4 at the top, i.e., grid position of 10, and then counts down three (the difference between 4 and 1) to place 1 at the grid position of 7. It is an imaginative strategy that allows him to keep the successful maximum column strategy. Unfortunately, it does not work. When the owl does not signal that 10:7 is a solution for 4:1, Jane takes over. She aligns the 4 column to the fourth grid position. Together they place the 1 column on the the first grid position to solve the problem. On the next problem, he reverts to the maximum column strategy but she solves it using the counting strategy. After that, the counting strategy dominates.

Then, there is a particularly tricky problem sequence that causes most learners problems: 1:2, 4:2, 4:8, 16:8 and 16:32 on a fixed grid (note that one column stays the same and the other has twice the opposing column value). At this point, the counting strategy has been firmly established. 1:2, 4:2 and 4:8 are easily solved. 16:8 presents an inherent challenge. The application only has a 10-division grid so it is not possible to place the 16 column on the sixteenth grid. The counting strategy no longer works. Many struggle here, trying things like placing the 16 column on the sixth grid position (Figure 1b), incorrectly supposing that the tenths digit does not matter. Remarkably, Jane and Tarzan do not have that problem. When presented with 16:8, she is initially confused ("huh?") as the established counting strategy will not work. He steps in with the maximum column strategy: "That [16 column] just needs to go to the top." She explains, "it is always half," and places the 8 column on the fifth grid position. They successfully apply that with the 16:32 problem. With the next problem (15:5), it does not work as well. There is no grid line that corresponds with one third of 10 (the highest grid position). Working on it, she figures out that she can place 15 at the ninth grid position and 5 at the third grid position to achieve the 3:1 ratio of the 15:5 problem. Again, the pertinence (i.e., whether it can be useful for a certain problem) of the maximum column strategy is refined through practice.

This example demonstrates several important features of collaborating on Proportion. First, given the right sequence of problems, children can arrive at useful strategies, which prove themselves useful in further problems. Second, when a previously successful strategy fails, the children are willing to abandon it in favor of one that works better. Third, though a strategy can be abandoned for some time, it can reemerge when faced with a difficult problem. Fourth, it is useful to have two partners to come up with possible strategies. Tarzan first discovers the maximum column strategy; Jane adopts it. She first discovers the counting strategy; he adopts it. He comes up with using the maximum column strategy for 16:8. She realizes its limitations for 15:5. Fifth, as Proportion is a reflective tool (i.e., the owl gives feedback about whether a certain configuration solves the problem), they are able to test strategies. The good ones are adopted; the bad ones are abandoned. Sixth, the adoption of new strategies is fairly fluid, requiring little discussion or causing unwieldy conflict.

Collaborating at the tablet

The pair starts in a collaborative mode, jointly manipulate the columns to solve the tasks. As they are in a

single-touch condition, this is not always easy. After seven minutes, Tarzan suggests that they take turns: "I'll do one, then you." Jane silently accepts. He tries to solve two tasks alone but gives up and lets Jane finish them. They smoothly switch back to a collaborative mode. After 20 minutes, Jane suggests the commonly used territorial approach ("You do this [left] column, I do that [right] column"). At the time, Tarzan is distracted and does not engage her suggestion. She ends up manipulating both columns. After the completion of that problem, Tarzan returns to the group, pulling the iPad to himself. Her suggestion is never employed. So, though suggestions for different working arrangements are made, they ultimately spend most of their time in an ad-hoc (anything goes) collaborative mode.



Figure 2. Configuration of learners at the tablet

Partly, they do not adopt the territorial approach because they cannot move both columns simultaneously. Partly, they do it because they both use their right hands. Most groups end up employing an approach featuring a centrally placed iPad and outside hand alignment, where the left partner uses the left hand and the right partner uses the right hand. This works particularly well with a territorial approach. That approach is never used as Tarzan uses his right hand. Both children predominantly use their dominant right hands (Tarzan: 60%; Jane: 98%). In such an alignment (Figure 2a), it is more comfortable for him to manipulate the right column and for her to manipulate the left column (i.e., the opposite of the territorial approach). As time progresses, Tarzan increasingly pulls the iPad towards himself (2b), allowing him to utilize both hands (45%). While this position clearly favors him as user, her right hand still has good access to the interactive surface and it does not negatively impact the collaboration. Jane uses both hands infrequently (5%), i.e., only when she is left to work a problem alone. Neither uses only the left hand. As Tarzan employs his right hand, the positions at the tablet are never symmetrical. His proximity to the iPad can cover up the iPad, making it difficult for Jane to interact or see. That said, she never complains and even goes to extremes (Figure 2c) to be able to see and interact with the tablet.

Both children are adept at negotiating who has control of the device. One common gesture is to lightly touch the other's hand to indicate that it should not be used. This subtle gesture works well: It never elicits a verbal follow up and does not disturb progress. He employs it 10 times and she 5 times. Bigger gestures to get rid of the other's hand appear over time. He employs them 13 times and she 4 times. Tarzan is quite dominant concerning the placement of the iPad: He turns it towards him (7 times), pulls the iPad to himself (11 times), and takes it into his hands (9 times) or even onto his knees (2 times). Jane usually accepts these movements and just continues participating in a calm style. She occasionally changes the tablet's position, turning it 6 times and pulling it to her 8 times. She never takes it into her hands or onto her knees. He controls who is working on a problem. Occasionally, he declares that he will solve the problem and pulls the iPad towards himself. She generally concedes. As he returns the iPad to her on the next problem (i.e., turn taking), this does not contribute to an equity problem. He also voluntarily passes the iPad to her when he is stuck and wants her to solve the task, typically accompanied by a verbal "you try it." In those cases, he observes how she solves the task.

Taming Tarzan

A defining property of this group is its interaction pattern. Tarzan regularly loses focus, becomes overly emotional and imposes his will. Like her fictional counterpart, Jane manages to deal with his eccentricities, allows him to be himself and makes the partnership work. Emotion regulation is considered to be an important phenomenon of collaborative learning, though not many good measures to capture its dynamics have been developed (Järvenoja, Volet & Järvelä, 2013). Here we detail how this partnership works.

The evaluation of on- and off-task behavior is a main and a first step in content analysis (Weinberger & Fischer, 2006). In terms of task focus, Tarzan varies widely: Often he is concentrated and excited; sometimes he

abandons the task to look around or to do something else. To better understand focus over time, we coded the behavior over the period on a per second basis into four categories: iPad use (when actively engaged with the task), observation (when watching the partner work), recreation (when doing things not related or relevant to the task, such as drinking a beverage) and goofing off (behavior that distracts the partner from the task). The first two categories can be considered on task while the last two categories are off task.

Task Focus	Over 40 Minute Session	Tarzan Jane
On Task (iPad Use)		77.00 % 59.04 %
		12.67 % 39.33 %
Off Task (Recreation)		9.88 % 1.38 %
Off Task (Goofing Off)	I III I I	0.46 % 0.25 %

Figure 3. Categorizing focus over the session

The results (Figure 3) are based on one coder. A second coder evaluated Minutes 13–18 for reliability; Cohen's Kappa was acceptable (κ =.611) for Tarzan and fair for Jane (κ =.346). As seen in Figure 3, the frequency of his off-task episodes increased over the session. His movements became bigger and his voice became louder (to the point where classmates asked him to be quiet). In contrast, Jane is consistently on task. She is rarely distracted by his actions and works by herself when he is doing other things. Only once (Minute 33) does she briefly join him in goofing off.

Remarkably, the driving force for his off-task behavior is his strong engagement with the task. Unlike Jane, Tarzan has access to an iPad at home and is used to playing games on the device. So it is not surprising that he treats Proportion as a game. Proportion has some game elements (positive feedback on success, levels) but intentionally avoids other common game elements (competition, scores, timed elements, narrative). When he finds out that others are at a further level, the gamification of the task kicks in. "Why won't it go to level eleven? I want to reach level eleven" (Minute 26). He frequently checks in with other groups to see how they are progressing (classified as recreation). For him, the game aspects appear to be motivating.

Though they are often in agreement, his emotional valence is significantly higher than hers. In Minute 12, she calmly remarks, "it is starting to get boring." He barks, "it is getting boring" and turns away. In Minute 14, he complains, "man, when are we ever getting to the next level? It is getting boring." She calmly responds, "I know" and they proceed on the task. To better understand the emotional valence, we coded the emotional valence on a scale of --2 to 2, where 0 is neutral, -1 is a loud negative remark and 1 is a loud positive remark (celebration after completing a level). Rankings below -1 and above 1 were reserved for extreme interaction, which happened rarely (never for Jane and a few times for Tarzan). Tarzan (μ =0.06, σ =0.25) had both a significantly higher mean and standard deviation than Jane (μ =0.01, σ =0.10). For both, the means were positive, indicative of a largely positive experience. Tarzan's higher standard deviation is both a function of higher frequency (he has more episodes that can be coded as something besides neutral) and valence (higher values to those episodes).

Throughout the session, his emotions are highly charged. On regular occasions, he claps his hands together in celebration on receiving "Correct!" feedback. He even questions why he does it, explaining that he can't control himself. His emotions are frequently manifested in his interactions with the owl, whom he directly addresses. At the beginning, most of these are negative: "dumb owl," "stupid owl," "fucking owl," etc. Over time, his treatment of the owl improves. He makes positive statements: "hello owl" and "[soothingly] okay owl." At one time (Minute 30), he even apologizes for saying "fuck." From then on, his interactions are positive or neutral: "the owl just said close." Overall, there were 67 interactions with the owl (40 negative, 17 neutral, 9 positive, 1 other). Critically, none of the emotional outbursts are aimed at his partner. The owl allows him to act out his emotions in a safe way: He is able to stay on task after such an emotional outburst. Jane does not engage his outbursts and that may be a reason that they never escalate. At one time, she emotionally supports him. He dramatically announces, "I'm too dumb, I can't solve any of these" and turns away. She replies, "that's not true, you've solved many of them." He joins back in.

Thus, though he easily gets off task, he easily gets back on. He does not go off task to avoid the task or to move the group away from it. As such, Jane is able to continue to work, seizing the opportunity to

monopolize the iPad. When he has calmed himself back down, he is able to rejoin her quickly. Though the occurrences are frequent, their duration is not. In total, his off-task behavior only accounts for 10% of his total time. Partly, the steady Jane tamed the wild Tarzan; partly, the steady Jane enabled Tarzan to tame himself.

Discussion: At-tablet collaborative learning

We have presented the case of Tarzan and Jane to show the potential of at-tablet collaborative learning. In several ways, tablet usage is similar to tabletop usage. As they use their hands to interact, the movements of the partner are easy to follow and regulate. Consequently, the children require little verbal interaction to collaborate. Even subtle gestures (e.g., tapping a hand to indicate that the partner should stop interacting with the tablet as the initiator has an idea to test out) can be utilized without being discussed. Though Tarzan's insistence on using his right hand often puts him in the dominant position, it does not hinder Jane from making contributions. A children working on a tabletop (Harris et al., 2009), the two were able to navigate the imposition of a single-touch interface without equity problems. As children working on a tabletop (Rick et al., 2011), the two were able to appropriate and build on each other's ideas.

In a couple of ways, tablets differ from tabletops. As particularly evident in this group, tablets can be moved and reoriented, leading to different body arrangements (Figure 2). Though this had the potential to lead to problems given Tarzan's propensity to grab the tablet, it did not. Frequently, position and orientation was used to communicate who had responsibility for a certain problem in turn taking (e.g., turning the iPad towards the partner to cede control). Because of their size, territoriality based on access need no longer define the interaction. Though many groups used the two columns of Proportion's interface as an implicit cue for how to interact (i.e., the territorial strategy), there is no physical impetus. Tarzan and Jane ignored this cue and it did not harm their interaction. A more substantial factor in shaping their interaction is that both primarily used their right hands.

Convergent conceptual change posits that two novices can benefit from at-device collaboration when using a reflective tool. This is certainly true for Tarzan and Jane using Proportion. Each is able to contribute and adopt ideas. Coordination losses are minimal. Collaborative learning is especially beneficial if both learners individually acquire knowledge, which in turn stimulates successful collaboration (Stahl, 2006). As Tarzan and Jane had a remarkably high learning gain (+11 points from pre- to post-test) compared to their peers (+2 on average), this could partially explain their success. In addition to cognitive support, this case demonstrates the emotional support that a partner can provide. On the pre-survey, Tarzan marked that he preferred to work alone; Jane marked that she preferred to work together. From our observations, she is a great collaborator. Our guess is that she would probably have worked well with anyone. In contrast, he probably would have had problems working with somebody who was not as supportive or who was easily distracted. We have highlighted how the calm Jane helped tame the wild Tarzan; however, the reverse is true as well: The boisterous Tarzan animated the cool Jane. In the end, the learners co-regulated each other productively. Both contributed, made significant progress, enjoyed the interaction and showed significant learning gains. Though she never interacted with other groups during the session, after completion, Jane proudly informed others of their outstanding task progress.

Implications: Beyond this pair

In this paper, we have presented a case of successful at-tablet collaboration. In critical ways, the interaction was extraordinary. The software was created specifically to promote co-located collaboration. The pair worked particularly well together. Hence, this interaction is not indicative of average at-tablet collaboration. But, we do feel that the case suggests important points about what can make at-tablet collaboration work. First, it demonstrates the process of acquiring new knowledge in a collaborative setting. The phases of discovery, application and pertinence can shed light on what makes for successful or unsuccessful collaboration. For instance, a group might fail in discovery as good ideas get drowned out by the partner (e.g., Barron, 2003). Alternatively, a group might fail in pertinence, not being able to solidify understanding and thereby not being able to transfer learning to outside the immediate context. Second, it shows how emotional regulation can be a significant part of successful collaboration. Roschelle (1992) concentrated on the cognitive benefits of colocated collaboration. In addition, co-located collaboration can have significant emotional benefits, motivating and engaging learners. When one partner loses interest, the other sustains the collaboration, allowing the partner to easily rejoin the task. As such, we would expect children working together to enjoy the task more and to persist longer when encountering difficulties. Third, it shows how adept children are at working together using a touch interface, with speech, gesture, body position, eye contact, etc. contributing to a smooth interaction experience where the benefits of working together greatly outweigh the coordination costs. This suggests further across-group analysis of how children communicate in this rich setting.

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Discovery Versus Direct Instruction: Learning Outcomes of Two Pedagogical Models Using Tangible Interfaces

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Abstract: We investigate the effect of using a tangible user interface (TUI) for discoverybased learning. For this purpose, we built EarExplorer, an interactive tangible system where students can manipulate and connect parts of the auditory system to rebuild a functional structure. An augmented reality layer displays sound waves and shows how they are transformed at various stages of the process. Our previous work suggests that TUIs are particularly good at preparing students for future learning; that is, students learn more when they can explore a novel domain with a TUI before compared to after receiving a traditional (e.g. lecture or text based) instruction. In this study, we isolated the impact of structured guidance versus no guidance during a hands-on TUI activity on learning. In one condition, students rebuilt the hearing system by self-driven discovery; in another condition they rebuilt it by following the step-by-step instructions of a video-teacher. We found that the first group ("discover") significantly outperformed the second group ("listen") by ~27% on the final learning test. To explain those results, we analyzed the TUI logs and explored how this effect unfolded with participants of different ability (i.e., low versus high GPA students).

Keywords: tangible user interface; collaborative learning; tabletop

Introduction

The recent decades have seen the development of a wide range of pedagogies based on constructivist learning theories that are often pitted against more traditional pedagogies (Piaget, 1998; Papert, 1980). They range from experiential and project-based learning methods to inquiry- and discovery-based approaches (Jong & Joolingen, 1998). However, there is an ongoing debate about the effectiveness and value of these approaches, compared to more structured and guided instructional methods (Kirschner, Sweller and Clark, 2006). In this paper, we argue that the effectiveness of the various learning methods strongly depends on the context in which they are used; in particular, we believe that certain technologically-enhanced learning environments are particularly well suited for constructivist-based approaches compared to more traditional instruction. In line with this belief, researchers have been advocating for new computational technologies as means for constructivist-based learning activities: when properly designed, new materials such as robotics, physical computing and tangible user interfaces (Papert, 1980; Blikstein, 2013) can be powerful building blocks in enriching such activities and facilitating their implementation in classrooms. Specifically, we are interested in exploring the potential of technologically enhanced hands-on activities for discovery learning. We build our work on the assumption that Tangible User Interfaces (TUIs) provide an ideal framework for using discovery-based learning activities as introduction for learners to a wide range of concepts: they form a highly controllable design space for interaction designers while providing all tools necessary for the creation of microworlds that enable intuitive interactions, physical manipulations and at the same time encompass rich information layers through augmented-reality techniques.

The main contribution of this work is to propose that augmented-reality-based TUIs are effective environments for discovery learning activities. In our study, participants engaged in a learning activity about the human hearing system on a newly designed TUI. One group used a discovery-based approach with minimal guidance, while the other group received video-based guidance throughout the activity. Our findings suggest that the discovery group seemed to gain more from the learning activity than their counterpart.

Theoretical framework: Preparing for future learning (PFL)

One of the main claims of constructivist approaches to learning is that students should explore or discover a given phenomenon before being told the normative explanation (Piaget, 1998; Bransford & Schwartz, 1999). The constructionist movement further stresses the importance of building, interacting with, and sharing constructed artifacts (Papert, 1980), as this provides opportunities for debugging one's own understanding by confronting in-progress theories with real-world feedback. The idea is to empower students by making them the agents of their learning process: their task is to actively construct knowledge by using their intuition and prior knowledge, build artifacts, and refine their micro-theories as they observe the performance of these artifacts in

the world. As such, students need to generate hypotheses, test them by gathering data, and construct a theory based on their observations. This process, as argued, could deepen students' conceptual understanding of a phenomenon (Bransford & Schwartz, 1999), as opposed to rote memorization of terminologies and procedures.

However, constructivist learning methods such as discovery learning are difficult to develop and implement in real-world classrooms. deJong and van Joolingen (1998) highlight three problems that students encounter in discovery learning: first, novices usually find it difficult to formulate a testable hypothesis with the data at hand; they tend to stick to their first hypothesis despite conflicting evidence. Second, designing a clean experiment to confirm or disconfirm a hypothesis is a difficult task, even for experts; this process becomes harder when the hypothesis is not clearly formulated. Third, finding patterns in the data beyond simple relationships is a skill that most novice students do not have. Combined with the lack of adequate teacher preparation, good assessment rubrics, and support materials, discovery learning is rarely used in classrooms in a sustainable way. Oftentimes, in the process of adapting discovery- or inquiry-based learning activities for the classroom, even progressive teachers fall back to more structured, less "authentic" approaches that overly simplify the activities (Chinn & Malhotra, 2002).

One theory that tackles those issues is the "Preparing for Future Learning" (PFL) framework (Bransford & Schwartz, 1999). This framework postulates that students do not necessarily have to discover the principles at hand during the discovery task. What matters is that they develop experiences and refined perceptions of the deep features of a phenomenon and develop their own corresponding theory. In their work, Bransford & Schwarz (1999) have students engage in activities on comparing contrasting cases (i.e. cases whose difference highlight core aspects of a phenomenon at hand); they then compare their own micro-theories with the accepted view of a concept. In our work, instead of constructing contrasting cases, we propose a well-designed discovery activity that serves the purpose of preparing students for future learning. More specifically, we are interested in using TUIs that incorporate physical and realistic items as interaction objects to introduce students to a new domain; additionally, we want to show that students will learn more from a lecture following the activity than a group that is guided through the task on the tangible interface.

Previous work and rationale of the current study

For the scope of this paper, we are interested in pursuing work started with another TUI developed in our lab about the role of TUIs as media that foster PFL. BrainExplorer (Fig. 1; Schneider, Wallace, Blikstein & Pea, 2013) is an interactive tabletop where users can explore the way the human brain processes visual information. Students take apart a physical replica of a brain while an augmented reality system displays visual pathways between brain regions. Users can then use an infrared pen to create lesions and observe the impact of their actions on the visual field of the subject. In a controlled experiment, we showed that students who first used BrainExplorer and then read a textbook chapter outperformed students who completed the same activities but in the reverse order (Fig. 1, right side). Our conclusions were that TUIs support students' elaboration of their own micro-theories and create an engaging point of entry for exploring a domain (Schneider, Jermann, Zufferey & Dillenbourg, 2011).

It is possible that starting with a hands-on activity in general is the one thing that caused higher learning gains in the previous study: as students were complete novices in the domain of the task, engaging with the TUI first gave students the opportunity to gain some initial experiences on which they could build on when receiving the formal instruction. However, we believe that the nature of the hands-on task itself had an impact on students' conceptual learning. For the current study, we manipulated the level of guidance students received in an explorative task on a similar TUI. The goal was to isolate the effect of self-driven discovery versus guided exploration on learning. The TUI was about the functioning of the human hearing system, a topic that was novel to the participants. Two groups started out with the TUI before receiving a text instruction on the topic; one group watched a video of a teacher explaining the function of each organ and how to connect them in the TUI. The other group rebuilt the hearing system without guidance. It is crucial to note the role of the activity design in the TUI: The activity was designed in such way that it provided the required range of various actions to allow for self-driven exploration, yet it was constraint enough to prevent participants to be overwhelmed with the breadth of possible actions or get off-track and focus on irrelevant aspects of the system. For instance, students only had to deal with eight tangibles, which allowed them to focus on the core mechanisms of the human hearing system; furthermore, additional information was only available on-demand through the information box. This is important as research shows that very loosely structured tasks that provide too many possibilities of manipulations are detrimental for novice students and can actually hamper their learning as they do not know what aspects to focus on, and how to make sense of the task at hand (Kirschner, Sweller and Clark, 2006). Within such a context, we hypothesize that the discovery group will be better prepared to learn from the text compared to the group that received a highly-scaffolded guidance during the hands-on task.

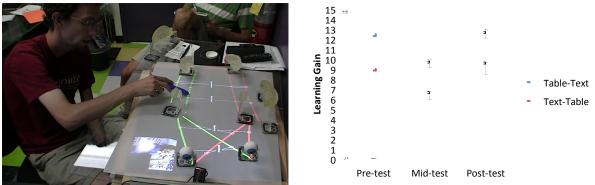


Figure 1. The BrainExplorer system. A user cut Mayer's loop and is reflecting on the effect of this lesion on the perceived visual field (on the bottom right corner)

EarExplorer

Design requirements

When designing EarExplorer, we started with the constraint of teaching a phenomenon that entails complex abstract concepts, yet is embedded in a highly spatial domain where one could take advantage of the "3Dness" of physical objects. These requirements are met by the human auditory system: it represents a system that transforms auditory information across various stages through a set of interconnected organs. Pilot interviews of novices who read a text about the hearing system revealed that students had trouble visualizing the different transductions happening in the ear (i.e. sound waves vibrate the ear drum with various sound pressures; the ear drum then moves the maleus to pass information as a mechanical movement; the ear bones then move the liquid contained in the cochlea and activate particular segments of the basilar membrane rolled in the cochlea). Novices also struggled with the spatial mapping of different sound frequencies on the basilar membrane. High frequency sounds traverse the membrane until it finds a segment thin enough to be activated. This mapping is counter-intuitive for novices, because we usually represent sounds on a number line from low (left) to high (right) frequency. Thus, the design of our first prototype focused on those two aspects: the propagation and transduction of sounds through the hearing system, and the spatial mapping of sound frequencies on the basilar membrane.

Design of the system

EarExplorer consists of a tabletop interface with 3D-printed tangibles tagged with fiducial markers. A projector displays an augmented reality layer by reflecting its image on a mirror held above the tabletop. A camera is attached to the mirror and detects the location of the fiducials on the tangibles (Figure 2). The starting screen displays three elements: the outer ear, which is the starting point of the activity (top left corner, Fig. 2); the auditory cortex, which is the end point of the activity (bottom right corner, Fig. 2); and an information box (bottom left corner, Fig. 2). Eight tangibles are arranged around the projected area. Students are asked to connect the tangibles between the starting point and the ending point to let sound waves reach the auditory cortex. Each tangible can be positioned in the information box at any time of the activity to display additional information about each organ. Users can use those hints to infer the correct sequence of tangibles and learn more facts about the function of each organ. The 8 tangibles (in bold below) serve the following functions:

- 1. The **speaker** generates sound waves at four different frequencies (low, medium, high, very high). Those four frequencies are displayed on top of the speaker with a specific color coding (from low to high frequency: blue, green, yellow, red). By flipping the speaker, users can generate a series of sound waves to test their system.
- 2. The **ear canal** then needs to be linked to the starting point of the activity (the outer ear) and carries sound waves to the eardrum. There are two feedbacks showing that the tangibles are successfully connected: first, students see the sound waves follow the ear canal; second, they also see the eardrum move back and forth in the augmented reality view as the sound waves reach the end of the ear canal.
- 3. The **ear bones** need to be connected to the ear canal. As the eardrum vibrates back and forth, the ear bones will provide a similar feedback: the augmented reality view will project the shape of the ear

bones on the tangible and animate them back and forth as the sound waves are reaching this part of the auditory circuit.

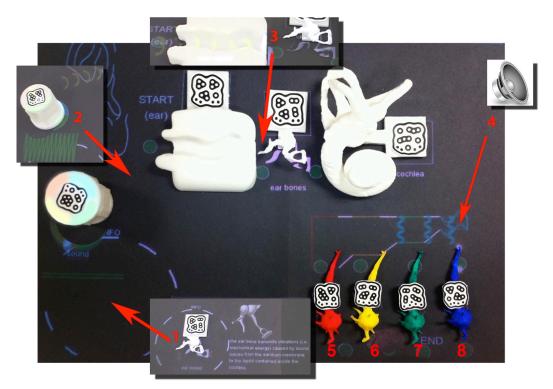


Figure 2. The EarExplorer Interface, after the users have connected all the tangibles in the correct sequence. They use the infobox (1) to learn about the different organs and connect them together; they then generate sounds at different frequencies with a speaker (2); sound waves travel from the emitter through the ear canal to the ear bones (3); finally, the sound reaches the basilar membrane inside the cochlea, activates a specific neuron and replays the sound if the configuration is correct (4).

- 4. The snail-shaped part of the cochlea contains the basilar membrane, which react to different sounds frequencies: the base is thicker and reacts to high-energy (high frequency) sounds; the apex (i.e. tail) is thinner and react to low-energy (low frequency) sounds. When students connect the cochlea to the ear bones, they see the basilar membrane being unrolled bellow the tangible. To stress this transition, a short video pops up in which a teacher reiterates that the membrane is unrolled to facilitate their task.
- 5-8. In this step, **four neurons** need to be correctly sequenced bellow the cochlea to rebuild the basilar membrane. Each neuron is associated with a particular thickness of the membrane, and a particular sound frequency. Each neuron is color-coded according to the coding scheme displayed on top of the speaker (from low to high frequencies: blue, green, yellow, red). We simplified the behavior of the system to provide an intuitive feedback when a sound wave reaches the basilar membrane: if the order is correct, users will see the part of the membrane associated with this neuron vibrate, followed by electrical potentials travelling through the neuron (Fig.2, bottom right corner, blue neuron), and the audio sound being replayed. If the order is incorrect, the membrane does not vibrate, the electrical potential does not reach the brain and no sound is played.

Method

Participants

38 college-level students took part in this study (average age 22.5, SD = 6.2; 26 females, 12 males). Participants completed the experiment as a requirement of a psychology class. The pre-requisite for registering was to not have any prior knowledge of the human hearing system. This population of students hence was very likely to be novice learners when it comes to the human hearing system.

Materials

The first activity involved rebuilding the human hearing system using EarExplorer. Students had 7 objects that they needed to connect between the outer ear and the brain: an ear canal, several ear bones, the cochlea and 4 neurons, as outlined previously. In the "listen" condition, students followed a step-by-step recorded guidance of a professional instructional designer. The instructional designer was not aware of our research hypotheses and was asked to make the learning material as engaging as possible. In a second activity, participants were asked to read a two-page summary describing the human hearing system. We retrieved the text from an educational website, whose goal is to simplify complex concepts to make them more accessible to a wider audience. The original text was four pages long; we removed paragraphs where the level of details was beyond the learning goal of this activity.

Finally, the learning test asked students to: 1) label the organs of the earing system; 2) describe various sound waves and asked which parts of the basilar membrane would vibrate at those frequencies; 3) compare the effect of various kinds of lesion (e.g. do broken ossicles have the same effect as piercing the eardrum?); 4) describe which part of the basilar membrane should be numbed to lose sensitivity to certain frequencies; 5) map the frequency range of various animals (bats, dogs, mice) inside their cochlea; 6) describe how sound is propagated from one organ to the other. Each learning test (pre, mid, post) had small variations in the questions.

Design

We used a between-subject experimental design (Fig. 3): in the control group, students followed the instructions of a teacher demonstrating how to build the human hearing system on a video ("listen"). In the treatment group, students built the hearing system without guidance ("discover"). The teacher used EarExplorer in the video, and described each piece of the TUI as well as each of the steps necessary to complete the task.

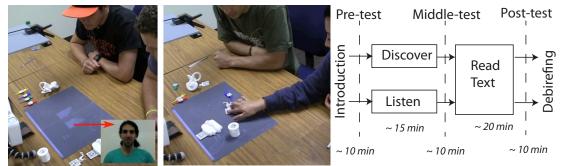


Figure 3. The two experimental conditions of our experiment (left: "listen", with the video of a teacher guiding the students through the activity; middle: "discover", where students rebuild the earing system by trial and errors. Right side: the experimental design of the activity.

Procedure

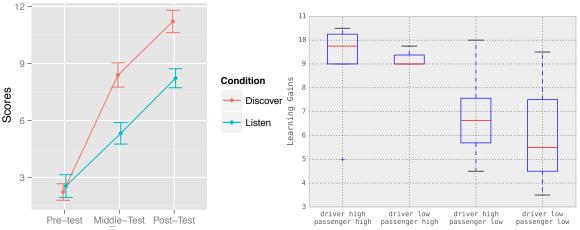
We ran the study in 4 consecutive days, over ~20 hours with 38 participants, doing the study in pairs. Each pair was formed randomly. Each pair had an hour to complete the study. Upon students' arrival, an experimenter explained that they would be working on a collaborative task and described the structure of the study (i.e. pretest, hands-on activity, middle-test, second activity, post-test). Students then took the pre-test, which all participants finished in less than 15 minutes. Participants then completed the first activity. In the "listen" condition, they were asked to rebuild the human hearing system by following the instructions of a presenter. Participants in the "discover" condition were asked to build the human hearing system by free exploration and by using the information box. Both conditions watched the same two-minute video describing the problem and the system: "John is deaf because his entire auditory system is missing. As you can see, there is nothing between his ear and his brain. Your goal is to help John hear again by rebuilding his auditory system! [...] At the bottom left corner of the table, there is an information box. By putting objects in this circle, you will be given more information about each piece of the auditory system". Students had 15 minutes to complete this task. They then took the mid-test for the next 10-15 minutes. During the second activity, students read a text describing the human hearing system and completed an activity where they analyzed different shapes of the basilar membrane and predicted the effect on the auditory range of the subject. They then recreated the shape with EarExplorer and compared their prediction with the output of the system. Finally, students were asked to take the post-test and were debriefed; we also informally asked them their opinion on the educational value of our system.

Coding

The learning test was coded in a binary fashion (correct / incorrect). Since the last question was open-ended, students received 1 point for a correct answer, 0.5 point for a partially correct answer, and zero points for a wrong answer. Log files were collected during the two activities involving EarExplorer. We logged information when a fiducial was added and removed from the table, when a new connection was created, when sound waves were generated, and how many times the info-box was accessed. Additionally, we categorized each participant in a binary manner as being either the "leader" or the "follower" in the activity. This distinction is motivated by the work of Shaer, et al. (2011), who noticed that pairs of participants tended to assign "roles" to their members; for instance, in collaborative tasks there tends to be a "driver", who is physically active and controls the interface, and a "passenger", who is physically inactive and merely proposes verbal suggestions. Those profiles of collaboration allowed us to further analyze the collaborative dynamics of a group.

Results

The results supported the hypothesis that subjects in the "discover" condition learned more than subjects in the "listen" condition (Fig. 4). We subtracted the pre-test from the middle and post-test to compute learning gains, since students in both groups scored very low on the pre-tests and avoided a ceiling effect. A multivariate ANOVA showed that participants in the "discover" learnt significantly more after the first activity: F(1,35) = 22.11, p < 0.001 and after the second activity: (F(1,35) = 16.15, p < 0.001. There was no significant difference on the pre-test: F(1,35) < 1.



<u>Figure 4</u>. Left side: results on the learning tests with regard to the two experimental conditions. Right side: learning gains by types of group (e.g., "driver high, passenger high" means that both the leader and follower in the group were above the median split computed on the students' GPA).

We analyzed the log files at the dyad level, since the system cannot differentiate between users. As such, we only have 20 data points and thus we will also report results where the p-value is below 0.1. A multivariate ANOVA revealed that participants in the "discover" condition did more manipulation with the tangibles during the two learning activities with EarExplorer: F(1,14) = 4.03, p = 0.064 (number of actions for the "discover" condition, mean=162.56, SD=52.53; for the "listen" condition, mean=132.89, SD=25.55). They also consulted the info-box more often: F(1,14) = 3.40, p = 0.087 (for the "discover" condition, mean=14.22, SD=16.71; for the "listen" condition, mean=3.33, SD=1.22). Interestingly, the number of times that participants accessed the "infobox" was positively correlated with higher learning gains on the middle-test: r(18) = .55, p = 0.018. This suggests that that part of the learning, as measured with the middle-test, happened in the interaction with the information box, and that students in the "discover" condition were more likely to consult it.

Effect on students' school proficiency (GPA)

As a post-hoc analysis, we wanted to see if the effect would hold for students of different abilities. To this end, we categorized participants as being below or above a median split computed on their GPA. While there was no significiant difference between groups in terms of students' GPA across the experimental groups, there were differences between pairs when classifying each student as being the "driver" or the "passenger" of the interaction (Shaer & al., 2011). The driver is the student who decides what the group does next, manages turn-taking and tends to be more physically active. The "passenger" takes less important decisions, tends to be more

passive and often merely proposes suggestions that need to be approved by others. There was not difference between drivers and passengers in terms of their learning gains. However, when this factor was crossed with a binary variable representing students' GPA (0 = below the median, 1 = above the median split) we found the following effect (Fig. 4, right side): As expected, groups with two proficient (i.e. both have a GPA above the median) students (first boxplot) had the highest learning gains and groups with two less proficient (i.e. both have a GPA above the median) students (fourth boxplot) had the lowest learning gains. What is interesting, though, is that being in a group with a low-GPA driver will make students more likely to learn: F(1,37) = 5.26, p < 0.05 compared to groups with a low-GPA passenger. Descriptive statistics suggest that this is more likely to be the case in the "listen" condition (mean = 9.00 for low GPA passengers versus 5.50 for high GPA passengers) compared to the "discover" condition (mean = 9.04 versus 8.83 for high / low GPA passengers). We did not test for significance for those results due to the low sample size of each group.

Users' comments on EarExplorer

Students' response was overwhelmingly positive. One participant said that she "would love to use a system like that in the classroom". Another mentioned, "It was nice to be able to build your own thing". The novelty of the interface sometimes had a negative effect on some students: some students stopped working on the task to understand where the projection was coming from and how the system could locate the tangibles. One even said "at the beginning I was more interested in understanding how the system worked than working on the task".

Discussion

In this paper we described the design of an educational TUI that supports students' discovery of the human hearing system. Our design was strongly influenced by interviews with students, as well as brainstorming sessions with experts in neuroscience. Even if our first prototype is in the early stage of its development, users responded positively to its design.

Our main contribution is an empirical study extending previous results found in our lab that that an exploration task on a TUI prior to reading a text instruction leads to higher learning gains than the other way around. The current study manipulated the level of guidance (close guidance vs self-driven discovery): we found that students who built the human hearing system with EarExplorer without guidance improved their learning gain from pre to post test by $\sim 25\%$ compared to students who followed the step-by-step instructions given by a teacher. Additionally, we found that students in this condition were more likely to take advantage of additional resources that provide relevant information to the task. We also qualitatively observed that minimally guided instruction facilitated students' exploration by having them produce incorrect systems, while students who followed the instruction of a teacher always immediately produced a perfect solution. This tendency to explore the problem space is supported by research showing that students *need* to make mistakes when learning about new concepts (Kapur, 2008). Thus, our findings suggest that a well-designed TUI activity for self-driven discovery might prepare them to better learn from a text-based instruction compared to students following stepby-step instructions. In order for such a TUI to be considered well-designed, the system does not only have to allow students to make mistakes, which could be achieved simply by increasing the complexity of the activity. Importantly, the system has to enable students to act on these mistakes such that the action advances their understanding of the phenomenon under investigation. This can be achieved by designing implicit scaffolds into the TUI. In EarExplorer, the scaffolds consist of the restricted number of tangibles, their shapes, and the animation upon correct connections. Without these implicit scaffolds, we believe that the self-driven discovery activity would be too unstructured for the students to learn from their actions and mistakes.

Finally, we found an interesting interaction effect between students' school proficiency (as measured by their GPA) and the group dynamics (i.e., who is driving the interaction): Groups with a low-GPA driver and high-GPA passenger scored higher on the test compared to groups with a high-GPA driver and a less proficient follower. Followers who are less competent than their peers were less likely to involve themselves in the activity, because it might seem that they did not believe that they could make a significant contribution, or because they were put in a clearly passive observer role. When they took more responsibility (i.e. by being a driver), in combination with a proficient peer engaging in the activity with them, we saw those students perform as well as high-GPA participants. It is important to point out that the students did not know anything about each others' GPA scores. Hence, this result suggests that group activities are more beneficial for dyads when the less proficient students were least likely to gain anything from the task. As such, this provides some insights on how to socially engineer group activities, as we believe that mixed-proficiency groups have advantages that both benefit the less proficient and the more proficient students.

Conclusion

TUIs possess an untapped potential for introducing students to new concepts. Previous research on interactive tabletops mostly focused on tangibles as interaction devices (e.g., Shaer & al., 2011). Few researchers have tried to fully exploit the representational effect TUIs for discovery-based learning. Our contribution is to provide preliminary design principles and empirical results to this new domain.

Taken together, our results suggest that educational TUIs better support learning when novice students have the possibility to explore the activity without explicit guidance compared to following step-by-step instructions. In order to build their intuition, students need the freedom of trying things, making mistakes and revising initial ideas to build their own micro-theories of a phenomenon. Just physically going through each step of the activity was not enough to build that prior intuition. An important feature of TUIs designed for discovery learning activities is that they allow designers to construct a rich space that enables a big variation of interactions, and keeps the activity complex and realistic, while at the same time cutting out unnecessary noise, and restricting the space of possibilities to prevent students from getting overwhelmed. By offloading explicit guidance to implicit design features, TUIs seem to be well-suited for novice students engaged in discovery-based activities. As such, TUIs have the potential to open the door for authentic learning activities into the classrooms in an effective way. If we find out more about how to use TUIs for this goal, we might concretely contribute to enriching students' experiences in schools in a sustainable way.

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Using Situated-Action Networks to Visualize Complex Learning

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Abstract: The purpose of this paper is to show how Situated-Action Networks (SAN) is a viable visualization tool for representing the learning that happens as a movement from peripheral to more engaged forms of participation in a social activity. In taking action as the unit of analysis, persons, speech acts, and artifacts are considered as the nodes in a functional model of learning. This method is illustrated by a simple proxy where a graduate student takes the place of a pilot apprentice who learns how to land an airplane in a computer simulation. Findings show that the SAN's sociographs and the learning trajectory plot display the interconnected complexity of the learning that occurred at various forms of action as a result of participation. Further work and limitations of this method are discussed.

Keywords: activity theory, distributed cognition, situated learning, social network analysis

Introduction

The purpose of this paper is to explore a visualization tool called *Situated-Action Networks*. Inspired by sociocultural approaches to learning (Brown, Collins, & Duguid, 1989; Cole, 1996; Lave & Wenger, 1991) and through the analytical lenses of activity theory (Engeström, 1987; Roth, 2007; Vygotsky, 1978) and distributed cognition (Hutchins, 1995; Hutchins & Klausen, 1996), Situated-Action Networks can offer new insights as to how the learner's traces can be analyzed to generate complex visualizations of the learning process. Similar to Epistemic Network Analysis (ENA, Shaffer et al., 2009), Situated-Action Networks focus on the observable interactions in various forms of social activities. In shifting the unit of analysis from cognitive processes to social activity, this form of visualization accounts for the social dynamics, tracing the learner's trajectory of participation from the periphery to a more engaged form of participation (Lave & Wenger, 1991). Building on Social Network Analysis (Wasserman, 1994), various descriptive network indices can provide useful information about the learner's level of participation in the social activity. I illustrate such a model with the use of a simple proxy of participatory learning where a graduate student takes the place of a pilot apprentice who learns how to land an airplane in a computer simulation.

Learning as a process

We take *action* as the unit of analysis. According to activity theory (Engeström, 1987; Leont'ev, 1974; Roth, 2007; Vygotsky, 1978), an action stands as the mediational link between a subject and an object. In this dialectical sense, actions are processes that connect two qualitatively different expressions of the same unit: in actions, subject and object are two constitutive elements that cannot be considered independently from each other (Roth, 2007). The idea that both subjects and objects are opposite but mutually constitutive parts of the same unit has important consequences for what, and how, subjects and objects are included in a representation of the learning process. In our analysis, subjects and objects are both represented as nodes in a network. This idea is not new, however, and some antecedents can be found in Latour's Science and Technology studies (Latour, 1987) and some educational approaches inspired by his ideas (see for instance Shaffer & Clinton, 2006). Also, the theory of distributed cognition takes the system of cognition of both persons and objects as the unit of analysis (Hutchins, 1995; Hutchins & Klausen, 1996).

Two main kinds of actions are envisioned in SAN analysis: a) instrumental and b) communicative actions. Instrumental actions refer to the use of artifacts – as a transformative material process (e.g., hammering a nail) or as the consumption of a source of information (e.g., reading a ruler or a scale). Communicative actions refer to linguistically achieved (i.e., verbal or non-verbal) intersubjective actions. In this case, language *is* the object. Vygotsky (1986) conceived of language as a tool that shared the same ontological status as that of a physical tool. For Cole (1996), this ontological status is clarified by using the term "artifact" to refer to both linguistic communication and material tools.

The conception of learning that we bring to bear here can be defined as a *micro-genetic* change in the pattern of actions. A pattern of actions represents the regularities of the learner's actions as well as the actions from all the other participants in the situation. That is, the connections between subjects and objects through actions in a regular manner. A micro-genetic change can be considered as a small developmental change that occurs as a consequence of an appropriation of the social practices (Cole, 1996; Roth, 2007; Vygotsky, 1978). In this sense, learning would not be necessarily a change in the apprentice's mind, but rather a change in her

participation – because the situation later displays a rather different pattern of actions. Therefore, learning is not observed as the acquisition of any kind of knowledge, but of a *knowing how* to go about doing things in practice (Greeno, 1998). This way of understanding learning has important consequences for how we should represent it. At the level of the analytical model, a learning process is better represented by a functional, rather than a structural, model (Roth, 2007). A structural model represents the elements in a situation, such as participants and instruments; for instance, a student and some weights, a notebook, and a scale. A functional model represents the actions that take place in that situation; for instance, the weighting and the note-taking. Because the pattern of actions in a situation can develop and change after participation (i.e., after the learning occurs), the process of learning is captured by two or more functional models displayed at different points of time. The changes in participation that occur in small periods of time (e.g., one or two hours) are regarded as microgenetic changes (Vygotsky, 1986).

Situated-action networks

Our model uses Social Network Analysis (Wasserman, 1994) in a broad sense. In our analysis, nodes represent participants, artifacts, and speech acts. Actions constitute the links between nodes; that is, one action is represented by a link between two nodes. In SAN, the number of nodes depends on the number of participants, artifacts, and speech acts in a situation. In addition, the links between nodes are quantified by the amount of similar actions belonging to the same category (i.e., links that relate the same person to the same speech act category or the same instrument). We assume that the situational and organizational constraints would allow us to quantify the occurrences (cf. Schegloff, 1993) of these types of actions that relate persons, speech acts, and artifacts in a learning activity. The method can be outlined in four steps. The first step is to create a raw data matrix where nodes and actions are recorded throughout segments of time (e.g., 1 minute or 10 second intervals). Second, a number of segments is subset depending on the starting and ending point of a socially meaningful activity (e.g., a 45 min class or a 10 min class activity). Third, an adjacency matrix is produced from the raw data matrix. And, fourth, a graphic representation is created.

For instance, take a simple scenario where two children are solving the Hanoi-Tower problem collaboratively. The two children, the materials they use, and the types of utterances they make, are all represented by nodes in this situated-action network. The actions are links between nodes, that is, one action links a subject to the object of that action. In the example, let's consider what types of nodes and actions are present. Let's suppose that child A tells her partner "Move it to the left", pointing at one of the wooden blocks; then child B moves the block to the left. In this particular case, there would be one node per child, one type of utterance, and one wooden block. This simple case depicts a sequence of two actions, one that links the utterance by child A and one that links the moving of the block by child B, or in network notation, g = ((Child A, Talk), (Child B, Move)). One can examine this interaction between child A and B more closely and include a link between the utterance and child B because this utterance was intended to her. In network notation, g = ((Child A, Talk), (Talk, Child B), (Child B, Move)) (see Figure 1).

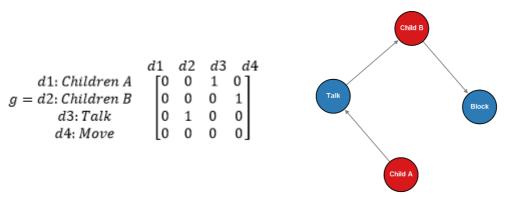
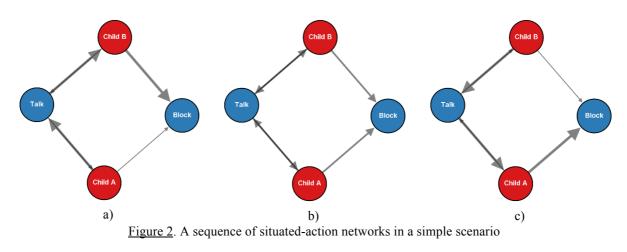


Figure 1. Matrix and graphical representation of a functional model

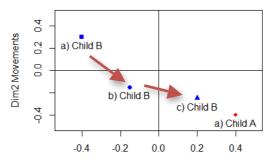
In comparing several of these representations over various activities, these networks reveal informative changes in the pattern of actions. The thickness of the lines can be used to represent the density of the actions between pairs of nodes. Various network indices (e.g., degree and centrality of nodes) can supplement the analysis, and can be used as a proxy of the learner's level of participation in the social activity. For instance, in our simple scenario, let's suppose that child B was learning how to solve the Hanoi-Tower problem, and child A

was the more capable other (see Figure 2). In the first attempt, child A gave a lot of directives as to what actions were to be taken and child B moved the blocks as instructed. In a second attempt, both children were talking and moving the blocks equally. And in a third attempt, the roles were inverted in the sense that it was now child B who was able to tell child A what actions were required to solve the problem and child A moved the blocks.

In addition, the novice's learning trajectory toward more engaged, expert-like participation can be displayed by plotting each network's center of mass in a 2-dimensional plot using the first two principal components. A principal component analysis is a statistical method that uses the eigenvalues from the adjacency matrix to create a linear combination of the nodes so as to cluster the most important ones (i.e., the nodes that carry the most weight) in the first dimension and a second linear combination with the second most important nodes for the second dimension. Each dimension is named after the dominant node that accounts for the most weight in the function. A 2-dimensional plot uses the first two principal components to represent the linear combination of the two most important clusters of nodes with the greatest weights. Because these dimensions are metric free, the numbers on the axis are arbitrarily set to have a mean of 0 and a standard deviation of 1. Using the principal component scores from the adjacency matrix, a center of mass is calculated as the multivariate centroid for a person in a particular iteration of the activity. For instance, the progression of the center of mass from our previous example would show that the density of actions of child B progresses (throughout the various iterations of the activity) towards that of child A in the first attempt (see Figure 3). As can be seen, the first center of mass for child B in (a) is high on movements but low on talk, and the progression shows how the importance of movements goes down whereas the importance of talk goes up toward the third center of mass (b). To illustrate the application of Situated-Action Networks, I bring the case of a graduate student who learns how to land an airplane in a computer simulation with the support of a more knowledgeable other.



Learning Progression



Dim1 Utterances Figure 3. Child's B learning progression represented by the trajectory of his center of mass

A brief example: Learning how to land an airplane

Methods

This example is a proxy of a naturalistic complex activity: the participation in the navigation and landing of an airplane in Microsoft Flight Simulator X. The goal of the learning activity was to support the learner's recognition and use of both the *navigation* indicator (GPS), and the *attitude* indicator (Artificial Horizon) to aid his performance in landing the aircraft. The purpose of the analysis was to visualize the progression of the learner's participation while toggling between the roles of the pilot and the copilot in the cockpit through repeated iterations of the activity. Seven activities were designed and conducted in a conference classroom, with a projector, a laptop, and a joystick (see Figure 4). The first activity was a pretest, the fifth activity a posttest, and the last two were near and far transfer activities. The total implementation lasted 2 hours. The participant was a convenience sample of a volunteer graduate student friends with the author, where the latter acted as the expert pilot because of his expertise with the simulator. The research question was: How does participation in several iterations of the activity shape the learner's participation in the activity, that is, his landing of a plane? The analyses were conducted with two main sources of data, a) talk and b) instrument use.



Figure 4. The research setting

Talk

Transcriptions were carried out to capture the textual talk at the expense of detailed nuances of pronunciation and timing. Our assumption was that the cockpit conversation would reveal the level of understanding of the piloting process (speed and power, altitude and speed, flaps and speed, etc.). Also, because these utterances have a dynamic and action-oriented nature (Schegloff & Sacks, 1973), grounded qualitative codes were produced to reveal the intended use of each speech act (see Table 1). Thus, an action would link the actor to a talk code – for instance, g = ((pilot, question), (copilot, answer), ..., (pilot, reflection)).

Code	Definition	Example
Question	Asking a question	"What is the altitude I have to descend to?"
Answer	Answering a question asked	"Descend to 2000 feet"
Assent	Acknowledging a previous utterance	"Okay, descending to 2000 feet"
Caution	Cautionary statement	"Careful, you are a little too high"
Fact	Giving an objective fact	"Your speed is 70 knots"
Assistance	Providing direct assistance	"You are going too fast, I'll setting flaps to 20 degrees"
Prompt	Prompting a suggestion	"Make a right turn now"
Reflection	Pondering some facts and relations	"If I move the flaps down now then it will slow me
		down, right?"

Table 1: Grounded codes for the cockpit talk

Instrument use

Video data was analyzed to capture the density of the instrument use in five areas: a) pilot's gaze, b) joystick, c) throttle, d) flaps, and e) landing gear. The pilot's gaze was mostly directed at two distinct places: i) at the instrument panel or ii) at the screen where the simulation was projected. Our insight for coding the gazing behavior this way, perhaps due to the researcher's prior knowledge with the flight simulator, was that the coordination between the instruments and the screen is an important part of the piloting activity because it reflects the pilot's awareness of the plane movements. In addition, the use of the joystick and throttle were

counted as an action if the pilot pushed or pulled the controls. As the copilot was responsible for activating the flaps and the landing gear, we tallied those moments as actions as well.

Results

Instrument use

How did the learner's instrument use change after participation and what did it look like in comparison to the expert's? Results from the gaze tracking (see Figure 5) revealed that during the pretest activity the learner looked twice as much at the instruments (294 sec, in blue) as at the screen (156 sec, in red). During the posttest activity, this proportion was approximately equal (200 sec at the instruments and 216 sec at the screen). During the expert-led activity, results revealed that the expert looked more at the screen (229 sec) than at the instruments (121 sec). Not only was this total proportion different between expert and apprentice, but also the average gaze length. The learner's average gaze length was 9.8 sec in the pretest activity, and decreased to 5.4 sec in the posttest activity. For the expert, the average gaze length was only 3.2 sec.



Figure 5. Gaze at instruments (blue) or at the screen (red)

These differences between pre and posttest and also between learner and expert are informative. During the pretest, the learner was trying hard to figure out how to read the *attitude* indicator, which is packed with information about the behavior of the plane. The apprentice had little time to observe how the "real" plane behaved (on-screen); instead, he seemed to be trying to respond to the information coming from the instruments and the directives from the copilot. Conversely, during the posttest activity, the learner seemed to better integrate these two sources of information, the instruments and the screen, into one blended space. His gaze moving back and forth more quickly from one source to the other supports this idea. On the other hand, it is apparent that the expert flies the plane looking primarily at the screen (the real behavior of the plane) and relies on the instrument information only to double check the correct performance of the plane (like dancing without looking at your feet). It seems that he does a rapid eye movement to glance at the instrument panel and then goes back to the screen, without losing sight of this latter for more than two or three seconds per time. The learner's posttest behavior seems half way between the pretest and the expert-like behavior. In the posttest, the apprentice did not rely on the instrument panel as much as in the pretest, but his gaze was not as quick as the expert's.

Similar changes occurred in the use of the controls. The expert seemed to have spent a lot of time moving the joystick and the throttle (71.8% and 63.5% of the total flight time, respectively). For the learner, we observed an increment in the use of these controls from the pretest to the posttest (from 34.8% to 71.2% for the joystick, and 18.4% to 46.9% for the throttle). We believe that these changes in the learner's behaviors are due to three factors: a) the development of a more fluid perceptual representation of the plane's behavior; b) the development of his motor coordination; and c) the development of an understanding of what the normative (or expert-like) practice should look like after his participation in the cockpit. We will elaborate on this latter point later.

Cockpit talk

How did the learner's talk change after participation and what did it look like in comparison to the expert's? Results show that during the pretest activity the learner did not talk much (only 18 out of 102 utterances of both participants combined), mostly assenting to the copilot's directives and asking questions (e.g., where to read the information from). The expert (copilot) often gave prompts about what, how, and when to do things. Conversely, during the posttest activity not only did the apprentice talk as much as the expert (42 out of 97 utterances), but also we observed a change in the type of utterances he made. In the posttest, the learner asked a

lot of questions (16 out of 97 utterances) about the plane's position, altitude, and speed. And more importantly, many of his utterances were in the form of reflections (13 out of 97 utterances), pondering about how speed and altitude relate to each other in the behavior of the plane, and how these were to change if one applied power or flaps. On the other hand, when the expert flew as the pilot, an analysis of the talk revealed that the expert used lots of self-reflections (20 out of 91 utterances). Also, there were a good deal of inquiries back and forth between the expert (pilot) and the learner (copilot), as reflected in the significant proportion of questions and answers in this activity. Again, an analysis of the learner's posttest activity shows that it looks half way between the expert-like behavior and the pretest. This pattern is not quite like the expert yet because the expert (copilot) gave a great amount of prompts about what to do (18 out of 97 utterances), and the learner posed a lot of questions as well as. It also is important to note that when the expert flew the plane, he was trying to instruct, so would naturally comment more than when in an expert solo condition or with another expert, therefore, this "expert" pattern might not reflect these latter types of activities.

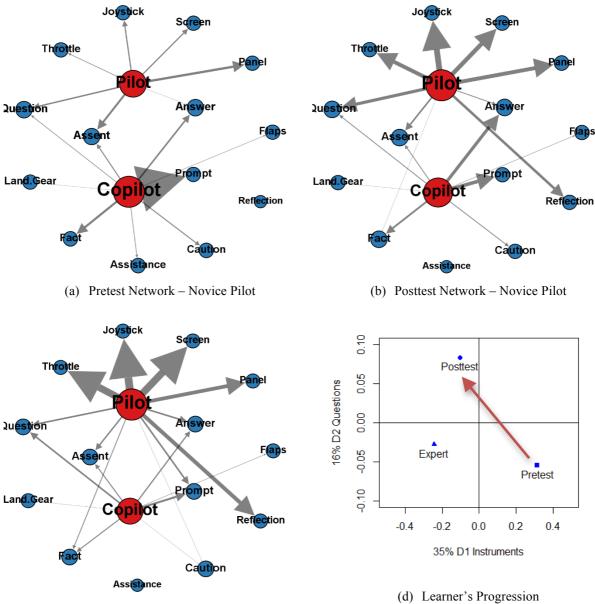
All in all, these trends of change make sense. During the first activity the learner was so overwhelmed by the ongoing demands of the piloting that he did not talk much and limited himself to follow directions on what to do and how to do it. In the posttest activity, the learner was a bit more experienced, was able to talk about the instruments with certain confidence, and was able to articulate his moves out loud. Certainly, the posttest talk was the product of previous interactions with the expert in that the meaning of the terms was situated in the use of the information coming from the instruments. We believe that not only was the learner appropriating the expert's discourse, but also his ways of reasoning about how the variables (e.g., speed, altitude, power) relate to each other. The following example illustrates the learner's emergent knowledge in practice. The excerpt lasts one minute and nine seconds. The copilot (the expert) is prompting the pilot (the learner) that he should reduce the speed because the airplane is going too fast. After this statement, the pilot ponders whether to use more flaps to reduce the altitude. The expert (the copilot) notes that the flaps do not reduce the altitude but the speed (because they create a drag force in the wings). However, the pilot (the learner) pointed out that a decrease in speed would also make the plane descend. And although the goal was not to descend yet (because they were not at the desired distance to the runway), this learner's reflection illustrates nicely why planes descend (not because the plane's nose points down but because of a reduction in its velocity).

Expert:	We are still far from the runway. Look at the GPS, it says we aren't close to the coast yet.
Learner:	Okay.
Expert:	You are going too fast, but try not to lose altitude.
Learner:	Can I use more F Flaps?
Expert:	To lose speed?
Learner:	Yeah, to lose altitude.
Expert:	No, the Flaps reduce speed, not altitude.
Learner:	But if we lose speed then the plane would lose altitude, right?
Expert:	Yes, it's a consequence of that.
Learner:	Yeah. So Yes, it would be good.
Expert:	Flaps 20 [Flaps go down]
Learner:	Ah, but I am gaining altitude again.
Expert:	Sure you do, because the flaps create resistance and lift, but the nose but putting the nose down it will increase the speed. Try to keep the nose as horizontal as possible.

Situated-action networks

Thus far, we have been asking questions about changes in individual pieces of information for the learner's actions. Now, we ask how the overall functional model of actions has changed. According to our original goal, we want to trace the development of the learner's participation. Therefore, SAN graphs were constructed to represent the relations, densities, and centralities of both actors during each activity. Three networks, one for the pretest, one for the posttest, and one for the expert, along with a graph for the trajectory of the center of masses, are presented in Figure 6. The first network, the pretest, serves as the baseline representation of the learner as a newcomer; the second network, the posttest, contrasts this baseline to a more engaged practice; and the third network, the first expert pilot activity, serves as a baseline to understand how much the expert exerted control on the piloting activity.

In the pretest network (see Figure 6.a), when the novice played the role of the pilot for the first time and the expert the copilot, the pilot's degree (i.e., the amount of the pilot's actions) was 36, and the network density (i.e., the average degree across all nodes) was 27. In the posttest network (b), which was after five landing activities in which the novice played the alternate role of the pilot or the copilot, it is apparent that his node played a more engaged role in the network. The pilot's degree for network (b) increased to 84, and the network density increased to 36.2. In addition, network (c) represents the activity when the expert played the role of the pilot. It shows a high level of engagement on the part of the pilot, with a high degree of 112 and high average network density of 40.6.



(c) Expert Network – Expert Pilot
 <u>Figure 6.</u> Situated-Action Netwoks for the novice pilot and the expert pilot

Finally, the participation progression can be seen in Figure 6.d, where center of masses are plotted along the first two principal components. The first component represents the amount of gaze at the instruments (and represents 35% of the variance) whereas the second component represents the amount of questioning (and represents 16% of the variance). It is apparent that the apprentice's dependency on the instruments decreased from the pre- to the post-test activity as revealed by a lower posttest center of mass on the first dimension, that

is, the center moved to the left. However, the apprentice also asked a higher amount of questions during the posttest compared to the pretest, as revealed by his higher center of mass on the second dimension, that is, it moved up in relation to the pretest. On the other hand, the expert's network has a low center of mass on both instrument and questioning dimensions. What stands out as really powerful from these network representations is that the researcher can track the learner's progression from several pieces of evidence (i.e., talk and instrument use) simultaneously. These multivariate analysis supports the visualization of complex, distributed activities in ways simple causation models cannot do. An examination of these networks can pick up subtle relationships between participants and practices that may not be possible from an analysis of disconnected preand posttest difference scores.

Discussion and conclusion

In this paper I have outlined a new visualization tool called Situated-Action Networks. With these visualizations researchers can gain insights into the learning process as a situated activity in which the learner's progression from peripheral types of participation are developed into more engaged forms. Because this tool supports the integration of actors, speech acts, and artifacts into one mode of representation, i.e., the network graphs, it allowed us to integrate the evidence of individual pieces of information to create together a complex visualization of the learning process. In the future, we will try to capture these interactions with the use of automated techniques. In some of our latest analyses we are exploring the use of point-of-view cameras (i.e., egocentric head-mounted cameras), digital pens, and infrared cameras that can capture anthropometric features. However, I have shown how this visualization technique can be produced from more traditional sources of video data, and I believe it can be useful in computer-based learning environments as well. In addition, we are thinking about how to incorporate relevant interactional information that the networks still do not represent, such as the moment-by-moment interactions between participants. For instance, showing how the pilot's use of the controls vary in response to the copilot's directions. Finally, I envision a possible use of situated-action networks to construct generalizable learning claims about participation levels in order to assess the learner's abilities in open-ended, ill-structured scenarios. A limitation of SAN is that, in order to provide the necessary points of comparison, it requires that several iterations of relatively similar learning activities, or of the same learning activity, are implemented.

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Emergent Roles and Collaborative Discourse Over Time

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Abstract: CSCL environments are intended to foster equal participation even when student roles are not assigned. However, roles may spontaneously emerge and result in distributed participation during collaboration, especially when students share and manage a single technology resource. We investigated how group discourse shaped emergent roles in a collaborative small group over the course of a 12-week science curriculum with simulated science experiments. Group members showed patterns in their discourse contributions in terms of content, function, and initiation and uptake of discourse topics. The emergence of these patterns stimulated role differentiation and stabilization. Conceptual discussion appeared to improve learning gains, while prioritization of task management detracted from learning. By tracking group discourse patterns, we can observe the process of role emergence in face-to-face CSCL interactions.

Keywords: roles, emergent, spontaneous, collaboration, discourse, learning outcomes

Introduction

CSCL environments are often designed to foster equal participation among group members without explicitly assigning specific roles. However, roles often emerge during collaborative learning (Strijbos & De Laat, 2010; Strijbos, De Laat, Martens & Jochems, 2005), influencing interactions and learning outcomes. When students present their developing understandings to the group, they open themselves to questions, critique, and requests for clarification or justification. This peer-review process, along with a focus on personal or collaborative goals, may impact how roles emerge from interactions (Strijbos & De Laat, 2010).

Roles, when self-assigned, are the personal undertaking of certain functions or responsibilities within the group that are designed to facilitate group progress towards a goal (Hare, 1994). Emerging roles develop spontaneously in response to a collaborative activity, as compared to scripted roles that are prescribed to facilitate collaboration and maximize learning gains (Strijbos & Weinberger, 2010). Roles emerge from social interactions that occur over time (Hoadley, 2010; Jahnke, 2010). Role formation or differentiation occurs when students impose responsibilities or functions on themselves or on other group members by positioning themselves, positioning others, or responding to others' positioning moves (Sarmiento & Shumar, 2010). Students who are comfortable divulging their developing knowledge may emerge as conceptual leaders or guides. Other students may take on group management or activity coordination tasks. Some students may deviate from expectedly "productive" roles and engage in off-task discussion. Ultimately the pattern of roles that emerges determines the efficiency of learning (Spada, 2010) and depth of knowledge co-construction for the group, with certain patterns of roles resulting in more effective learning (De Wever, Van Keer, Schellens & Valcke, 2010; Gu, Shao, Guo & Lim, 2015).

CSCL environments impact role formation because of the additional requirement of managing integrated technology during group discussion. By necessity, role establishment is more structured when a group shares a single technology resource during a face-to-face learning activity (Jones & Issroff, 2005). As only one student can manipulate the machine at a time, the student adopting this role becomes responsible for typing or entering inputs of information. He or she may seek group consensus on these inputs before entering them. In-group consensus becomes an issue of concern when session time is limited and task completion is favored over conceptual sharing or exploration (Bruhn, 2000).

In this study, we investigated how different types of discourse impacted emergent role formation within a collaborative small group. We also examined how different roles were associated with unbalanced learning gains for group members. Our research questions were: How do emerging roles shape discourse when students collaborate in a group? How does role differentiation impact learning gains for group members?

Methods

This study was part of the CoMPASS project (Puntambekar, Stylianou & Goldstein, 2007) designed to examine developing science literacy as students interacted with digital text and other scaffolded tools. The project included a 12-week design-based physics curriculum centered on concepts involving forces, work, energy and motion as applied to roller coaster design. In the classroom, students utilized the digital text, CoMPASS, and a

roller coaster simulation while collaborating in the same small groups of three to five throughout the unit. Students recorded notes in their scientists' journals, which prompted students to individually and collaboratively generate questions and hypotheses, experiment within the simulation, record observations and data, and make conclusions about physics concepts and relationships. Data relevant to this study included video and audio recordings of 14 simulation experiments and pre- and post-measures of physics conceptual understanding.

Participants

This study focused on a subset of students from the larger study sample. We selected one balanced-gender group of four sixth-grade students (N=4) based on relatively high variability in post-assessment scores and availability of video data for analysis. These students are identified as Michael, Scott, Sandra and Amy for this study. They participated in a classroom of 22 students composing six groups total. They attended a large suburban public middle school in the US Midwest (U.S. Department of Education, 2013). In the 2011-2012 school year, 85.1% of the students were white and non-Hispanic, and 18.7% were eligible for free or reduced-price lunch (U.S. Department of Education, 2013).

Procedure and measures

We analyzed data for general observations of trends in discourse. The first author noted that students in this subset of the sample tended to perform the same discourse moves throughout the curriculum. The same group also had highly variable learning gains as measured by a conceptual understanding assessment (see next paragraph). To further investigate this pattern, video and audio data recordings of 14 simulation experiments were prepared for analysis.

We used a CoMPASS-designed physics test ("Physics Fiesta") to measure conceptual change shown as pre-post differences in assessment scores. This test consisted of 29 questions pertaining to concepts and relationships involving forces, work, energy, friction, and Newton's Laws. Correct items earned one point while incorrect items were given zero points. A score of 29 points was the highest possible score.

Analysis

Qualitative analysis

We imported video and audio data into Transana data analysis software for synchronization and transcription. We transcribed a total of 2,759 turns of talk over 14 sessions. We compiled these transcripts in Microsoft Excel and evaluated for general patterns prior to in-depth analysis. We designed a coding scheme using group discourse as the unit of analysis to identify discourse moves associated with emerging roles (see Table A1 in Appendix). The two-dimensional coding scheme identified initiation or uptake of topics (Discourse Action) and content (Discourse Type) in turns of talk (Strijbos & Stahl, 2007; Hmelo-Silver & Barrows, 2008; Van Aalst, 2009). An external coder familiar with the project helped establish inter-rater reliability; inter-rater percentage agreement was 85.64% after an initial round of 10% of total codes (281 turns of 2,759 total) and 99.82% after resolving differences through discussion. The first author coded the remaining turns, using multiple codes when appropriate. The coding scheme was not applicable to 13.16% of turns. We collapsed codes into three categories: Conceptual, Procedural and Negotiation, and Social (see Table A1). We created discourse profiles for each student. We created CORDTRA diagrams to visualize discourse contributions over time (Hmelo-Silver, Liu & Jordan, 2009).

Quantitative Analysis

We calculated the frequencies and proportions of total and collapsed discourse codes. Proportions allowed us to evaluate patterns in discourse contributions for less dominant speakers whose contributions were obscured by more dominant speakers. Proportions of each discourse group by code were categorized into student profiles for comparisons. Dependent-sample *t*-tests were utilized in analyzing differences in discourse contribution frequencies between students and simulations (de Winter, 2013). Percentage learning gains were calculated for the Physics Fiesta assessment.

Findings

Emerging roles over time

We investigated role emergence by comparing proportions of discourse contributions for each group member over the entirety of the 12-week curriculum; a temporal examination of contributions to specific discourse types provided insights into role differentiation and stabilization. Table 1 shows the proportions of discourse types for each student; proportions were calculated as contributions to each type of coded discourse. Figure 1 shows the discourse contribution profiles for each student as total contributions, which were then subdivided into initiation (Initiating) and uptake (Following) of discourse topics.

Each student showed a unique pattern in contributions to discourse types. Michael was the greatest overall contributor to total discourse (1049 turns), followed by Amy, Sandra and Scott (729, 567, and 405 turns, respectively). When comparing individual student profiles for total discourse contributions, we see that Michael contributed the most to conceptual discourse (.224), Sandra to procedural discourse (.762), and Scott to social discourse (.221). Amy showed a mixed-discourse profile indicating more balanced participation. Observations of initiation and uptake of discourse topics reflected similar contribution patterns. Michael tended to initiate conceptual and social talk (.291 and .171, respectively), while Amy and Sandra initiated procedural talk (.754 and .800, respectively). Scott followed up on social talk (.281), while Sandra continued discussions related to simulation procedures (.740). Amy and Michael followed discourse topics of all types.

	Discourse Type	Scott	Amy	Michael	Sandra
	Conceptual	0.193	0.183	0.224	0.121
Total	Procedural	0.587	0.682	0.597	0.762
	Social	0.221	0.134	0.180	0.117
Initiating	Conceptual	0.214	0.172	0.291	0.106
	Procedural	0.630	0.754	0.538	0.800
	Social	0.156	0.073	0.171	0.094
Following	Conceptual	0.173	0.190	0.185	0.130
	Procedural	0.546	0.641	0.630	0.740
	Social	0.281	0.170	0.185	0.130

Table 1: Proportions of discourse contributions

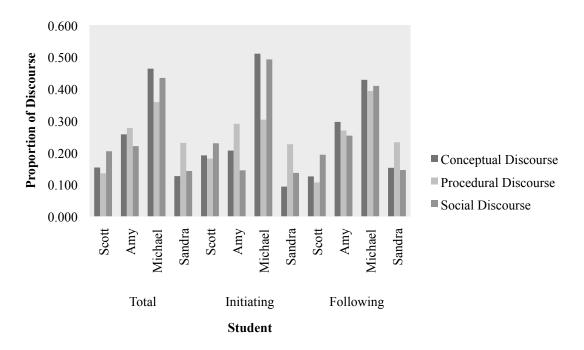


Figure 1. Student profiles of discourse contributions

We evaluated individuals' discourse contributions over the entire curriculum to explore a potential association between changes in students' discourse contributions and role formation. As students established roles, their contributions became more consistent. Dependent-sample *t*-tests were used to compare frequencies of student discourse contributions during simulations at beginning, middle and end time points of the unit (Sim1, Sim7, and Sim14, respectively). Results of *t*-tests are shown in Table 2. Amy and Michael contributed more from the beginning of the unit to the midpoint and from the midpoint to the end, but these increases were

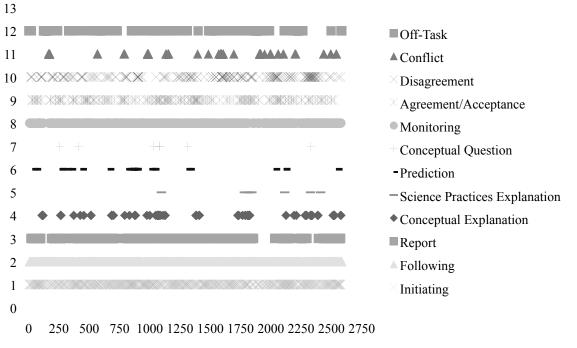
not significant (p = .074 and p = .388; p = .428 and p = .359, respectively). Sandra significantly increased her contributions from the beginning to the midpoint (p = .035) and continued to increase her contributions at a non-significant level in the second half (p = .616). Scott was the exception; despite a significant increase in contributions in the first half of the unit (p = .022), he contributed significantly less in the second half (p = .048).

	Paired			Std. Error	t-		Sig.
Student	Simulations	Mean	Std. Dev.	of Mean	statistic	df	(2-tailed)
Scott	Sim1-Sim7	-7.667	5.750	2.348	-3.266	5	0.022*
	Sim7-Sim14	6.333	5.955	2.431	2.605	5	0.048*
Amy	Sim1-Sim7	-5.000	5.441	2.221	-2.251	5	0.074
	Sim7-Sim14	-5.000	12.946	5.285	-0.946	5	0.388
Michael	Sim1-Sim7	-3.500	9.935	4.056	-0.863	5	0.428
	Sim7-Sim14	-6.167	14.945	6.101	-1.011	5	0.359
Sandra	Sim1-Sim7	-5.333	4.546	1.856	-2.874	5	0.035*
	Sim7-Sim14	-2.000	9.165	3.742	-0.535	5	0.616

Table 2: Dependent-sample t-test results for frequency of discourse contributions over time

*Result is significant at p < 0.05

We also evaluated whole-group discourse patterns over time. Frequency of contributions to different discourse types varied over time. Figure 2 represents how contribution frequencies changed over the curriculum (shown by Discourse Type; see Appendix). Reports were the most regularly contributed conceptual discourse type throughout the curriculum (326 turns). Conceptual Explanations were given more often in the first half and near the end, while Science Practices Explanations were mostly given at the end. Predictions were made more often in the first half of the curriculum; a similar pattern exists for Conceptual Questions. Monitoring, Agreement/Acceptance and Disagreement were procedural discourse types contributed with near-constant regularity. Social discourse was present mainly as Off-Task discussions. Statements of Conflict increased towards the end. The Initiating and Following contribution patterns indicated that students rarely continued a conversation topic for an extended period of time but frequently started new topics of discussion instead.



Turns of Talk

Figure 2. CORDTRA diagram showing whole group discourse contributions over 12 weeks

Summary of emerging roles

Overall, Michael emerged as the conceptual guide while Sandra managed the technology component and assumed procedural duties. Scott contributed to social discussion, primarily as continued engagement in off-task topics. Amy did not contribute a specific type of discourse but actively participated in conceptual and procedural discussions. Excerpts from the transcripts reflect this pattern (see below). Michael actively initiated and participated in conceptual discourse by predicting or explaining patterns in the data. Amy requested elaborations and justifications from Michael while aiding Sandra in maintaining group focus on the task. Scott listened to group debate and contributed his opinion when not participating in social discourse. The following excerpts are illustrative of the emergence of Michael's conceptual role, Sandra's manager role, and Amy's negotiation of experiment input values:

Excerpt 1

Michael:	It's going to be 3. 3.4 newtons.
Amy:	Wait, how many [joules] do you think it'll be?
Michael:	3.49 newtons. 3.49 newtons! It's going to be 3 joules. Going to be 3 joules. It's going to be $-$ aww, what? 2.9.

Excerpt 2

Amy:	I think we should do 3 anyway.
Michael:	I think we should do 2.5. That works.
Sandra:	It's not going to help if we take a vote. It's going to be two on two.
Michael:	'Cause 3 just stopped it too fast. It's not fair. It's not scientific-y.
Amy:	Let's just do it.
Michael:	No, it's not fair. Why do you guys think it's 3?
Amy:	Because, um, it takes, um, less [unintelligible] and less track to stop it and it's still safe and efficient.
Michael:	2.5 was more efficient. Uh, 2.5 is more safe, and it still doesn't take that much track.

Excerpt 3

Michael:	The velocity is going to be 4.43 m/s.
Amy:	Right?
Michael:	Work?
Sandra:	Yeah.
Michael:	Work. It's going to be 4.43 m/s. Yeah. And then the kinetic energy and the [total] mechanical energy at the bottom will be 5.9. I called it. I'm done. The velocity for all of them – it's just going to be 4.43 J. I mean 4.43 m/s. And then the kinetic energy is total final energy at the bottom is going to be the same as initial P.E. and total initial energy.

Learning outcomes

Learning outcomes were evaluated because of the potential impact of collaboration quality on learning gains. Pre- and post-measures of physics conceptual understanding were assessed with the Physics Fiesta test. Learning gains were calculated first as pre-post differences and then as percentages (difference in score was divided by the initial score). Michael experienced the greatest learning gain (~77%). Scott and Amy also showed learning gains (~11%) despite contributing mainly to non-conceptual discourse. Sandra demonstrated a loss of learning of approximately 17%.

Discussion

This study investigated how discourse in a collaborative small group shaped role emergence and how adoption of emergent roles impacted learning gains for each student. Using a small sample allowed fine-grained analysis of ethnographic data collected over multiple weeks of an entire unit, permitting generation of holistic student profiles.

Roles emerged over time as a result of individual contributions to group discourse. Each student demonstrated a dominant discourse type evidenced by proportions of discourse contributions (see Table 1 & Figure 1). The initiation and uptake of discourse topics also revealed student-specific patterns related to role differentiation. Students may have contributed more frequently to particular discourse types because of personal interest or proficiency in a specific responsibility or content area (Strijbos & Weinberger, 2010). For example, a student interested in conceptual relationships may state unsolicited hypotheses regarding what will happen next in an experiment. As students performed discourse moves, the group underwent a dynamic process of talk differentiation and distribution (De Wever et al., 2010; Hoadley, 2010). The performance and adoption of certain discourse moves by individuals over time structured group interactions and initiated role emergence (Strijbos & Weinberger, 2010).

Students' consistent patterns in discourse participation shaped role formation (Hoadley, 2010). As students adopted roles, the roles reinforced their discursive tendencies, especially in initiation and uptake of discussion topics. This reinforcement resulted in a stabilization of discourse contributions and thus persistence of roles through the end of the curriculum (De Wever et al., 2010). The dependent-sample *t*-tests indicated that a process of initial role formation and subsequent stabilization occurred via individual discourse contributions over time. Michael's non-significant increase in contributions indicated that he immediately established his role as conceptual guide. The other students showed greater increases in contributions in the first half of the curriculum, indicating a responsive role differentiation stage (De Wever et al., 2010; Hoadley, 2010). The lack of significant increases in the second half of the curriculum indicated role stabilization. The decline in mean contributions for Scott and Michael may be due to a discouragement of social discourse contributions with the exception of relatively rare conceptual discourse types. This likely resulted from the undertaking of conceptual talk by a single student (e.g. Michael), indicating that conceptual discourse was role-specific in this case. The consistency in procedural contributions may have reflected an urgency to complete the task in limited time.

Although the sample size of this study is too small to make claims about learning gains, the emergence of specific roles for each student may be related to learning gains or losses. Michael verbalized observations, explanations, and other types of conceptual discourse; he also experienced the greatest learning gain. Sandra, on the other hand, managed the technology for the group in each session while planning the task and negotiating input values. Her narrow focus on the task may have limited her participation in conceptual discourse, possibly contributing to her learning decrease on the conceptual assessment. Interestingly, both Scott and Amy showed modest learning gains despite Scott's participation in social discourse and Amy's balanced participation in all discourse. Overall, this discourse-role-achievement pattern aligns with the findings of Gu et al. (2015); the functions of particular roles lend themselves to variable conceptual achievement, with task management roles resulting in lower achievement. The initiation and uptake patterns also indicated short discussion lengths throughout, which may have limited potential conceptual gains.

Unfortunately procedural discussion pertaining to experiment planning and negotiation of input values predominated over conceptual talk. These findings align with those of Strijbos et al. (2005), who found that role behavior emerged through task planning instead of discussion of relevant concepts and principles. The preponderance of procedural talk may have reduced contributions to conceptual discourse because of limited session time, forcing conceptual and procedural ideas to compete for student attention. Students may have faced a dilemma between exploring data patterns and completing the assigned task. With limited time, students enacting the manager role may prioritize procedural discourse over exploratory conceptual talk out of necessity; their participation in conceptual discussion is reduced as a result. This limitation could be evenly distributed among group members so no one student is limited in conceptual discussion. Future implementations could a) expedite negotiation of experiment inputs by requesting justifications in advance, and b) schedule rotation of the technology manager role if single-student manipulation is stipulated (Strijbos & Weinberger, 2010; Gu et al., 2015). Spada (2010) has summarized alternatives to role rotation, such as intentional distribution of expertise.

The primary limitation of this study was the small sample size, which reduced the availability of parametric testing and limited generalizability. This study was designed to be an in-depth analysis of a single group's emergent role process, but future studies with multiple groups could determine if the pattern between emergent roles and learning outcomes is consistent. Replication could reinforce the association between observed discourse patterns and emergent roles and support a potential link between role differentiation and

learning gains. Comparison groups should include students of greater diversity in demographic backgrounds; our current study is limited in generalizability in that regard. Additionally, the assessment for physics conceptual understanding may have not captured full learning gains from the implementation as it was administered at the end of the school year and did not impact school grades, potentially altering the level of motivation or cognitive effort expended by students on this post-measure.

Implications and conclusion

The implications of this study mainly relate to the debate surrounding scripting of roles (Hoadley, 2010; Strijbos & Weinberger, 2010; Spada, 2010; De Wever et al., 2010; Strijbos & de Laat, 2010). CSCL environments are engineered to foster equal participation, but this may not occur for many reasons. While there are multiple studies of how to optimize scripting for collaborative groups, our study's focus on emergent roles in face-to-face technology-enhanced collaboration is unique. Students in CoMPASS classrooms are familiar with each other and have pre-existing perceptions or expectations of one another; these attitudes may influence the social reinforcement of emerging roles and discourse moves. These interactions are crucial to knowledge co-construction and should be facilitated so that students have equal opportunities to act in each role, at least temporarily, before role stabilization occurs. By rotating the roles within the group, especially those involving control of technology resources, we may improve the distribution of learning gains for group members. Further investigations into processes of role formation provide opportunities for curriculum designers to differentiate and distribute roles in ways that maximize collaboration benefits for each student.

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Appendix

Table A1: Two-Dimensional Coding Scheme for Student Discourse Analysis

Discourse Action	Description	Example
Initiating	Issuing a statement or question intended to begin a	"Who's going to be the group
	conversation about a specific topic.	leader today?"
Following	Following an initiation statement or question that	"If yours is confirmed, then mine
	continues the conversation about the same topic.	is confirmed."
Discourse Type	Description	Example
Conceptual		
Report	Statements that indicate observations and	"We don't have any kinetic
	interpretations of data at a superficial level, including	energy."
	definition, hypotheses, confirmation of predictions,	
	and opinions without reasoning.	
Conceptual	Statements that indicate reasoning, elaboration or	"I just like say velocity is
Explanation	clarification, justification, or proposition of a	dependent on speed."
	relationship between concepts.	
Science Practices	Statements that indicate non-conceptual reasoning for	"I was thinking about doing 0.3,
Explanation	suggestions; they must be rooted in the scientific	0.6, [and] 0.9 because we did a
	method.	lot of 0.2, 0.4 [and] 0.6."
Conceptual	Questions that are designed to seek information or	"Wait, how many [joules] do you
Question	request an explanation or clarification regarding	think it will be?"
	concepts.	
Prediction	Statements that predict a particular outcome, such as a	"It's going to be zero joules for
	dependent variable value.	the rest of them."
Procedural and Neg		
Monitoring	Statements or questions related to planning the task	"Okay, should we go with 0.25
	process, including preparing the simulation,	kilograms?"
	requesting suggestions, making suggestions (including	
	alternatives), seeking consensus, making and	
	verifying decisions, refocusing group members,	
	restating task constraints, and group policing.	
Agreement	Statements indicating a shared opinion and/or	"I like it, I like it."
	understanding (Van Aalst, 2009) or acceptance of	
	another's opinion.	
Disagreement	Statements indicating a difference in opinion or	"No, they're not."
	understanding (Van Aalst, 2009).	
Social	1	1
Conflict	Statements or questions indicating group dynamics,	"I never get a say in anything."
	specifically criticism of peers or the task process.	
Off-Task	Statements or questions regarding topics unrelated to	"Orange juice. Mmm. Would you
	task concepts or procedures.	like some [orange juice]?"

Design in Game-Based Learning

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Abstract: Educational games have shown promise as a technology that can improve learning, and education, but research has yet to produce games that can consistently and sustainably fulfill this promise. One reason to the shortcomings of research may be that game based approaches, including design approaches, have thus far focused on developing domain-based theories and methods of research and design and have tended to neglect design frameworks. In this paper, we identify design as an area that will be necessary to study in order to develop effective educational games and suggest that literature begins by presenting failure in design in order to identify what needs to be improved.

Keywords: educational games, learning, design research, design frameworks

Introduction

The last decade's interest in using games to help transform education for the 21st century has produced mixed results. The results are mixed in that, while games have been repeatedly shown to have the potential to contribute positively to learning and education, we still don't know how to consistently design games that are regularly used, that improve learning in predictable and desirable ways, and that require a reasonable and attainable amount of resources especially when sustained at scale. That is, similar to educational technology predecessors (e.g. LOGO), one of the major challenges that educational games faces is not whether they can produce good learning, but how learning games can be developed, distributed, used, and supported given present contexts. These challenges are not insurmountable, however they require addressing a major gap within design research literature centered on theories of design.

Design is generally acknowledged as essential for the development of education technology interventions that can effect authentic, local, and possibly large-scale change, as well as for conducting rigorous studies in messy environments (DBRC, 2003; Fishman, Penuel, Hegedus, & Roschelle, 2011; Penuel, Fishman, Cheng, & Sabelli, 2011). Despite its importance, design itself has been relatively under-theorized or at the very least, infrequently discussed in CSCL literature (though see Kirschner, Strijbos, Kreijns, & Beers, 2004). This is especially true in the burgeoning field of games research where the focus has been to test whether games can be useful for learning, rather than how games can be developed to provide long-term improvements (Clark, Tanner-Smith, & Killingsworth, 2014). For example, in describing the development of Quest Atlantis, a virtual world where student players can engage in pro-social and scientific narratives, Barab et al. (2004) use components of ethnography, design-based research, and action research to describe the conditions and processes that contributed to their design. As participant observers, they talk about how their designed technology was intended to "aid children in valuing their communities and in recognizing that they have important ways to contribute to their communities and the world" (pp 255). Conducting a "critical design ethnography" Barab et al. (2004) present a sense of why they created the program that they did, however the readers are left with little understanding of the relationship between how particular elements of their design came about (e.g. why was it digital, multiplayer, quest-based), how these elements evolved throughout the project and why certain designs were favored or emerged. As an even more specific example, consider that the authors reported that the game can be customized in order to fit local content and that it already contained over 400 stock quests that the teachers and players could choose from. The author's description leaves readers guessing with regards to how they ended up with this configuration of quests as a solution to improve flexibility or whether more quests or more robust versions of the current ones might offer better alternatives. The critical design ethnography they employed was useful in conveying a sense that the project required balancing multiple agendas and that the technology had to be flexible in its design, especially when moving across different contexts of play. However, the ethnography does not convey how the authors determined what they needed to do to the technology to make it flexible in the first place or a theory of design that would describe how to improve it in future versions.

The purpose of this paper is to spur discussion about design, particularly the design of educational games and their associated learning environments. Because game-based educational technologies continue to

gain popularity in formal and informal educational environments, theories and guidelines regarding the parameters of future designs are increasingly necessary, both to improve research and understanding of how games affect learning, but also to improve the designs themselves. In particular, what's needed are "design frameworks" (Edelson, 2002), which can be produced through design studies and present "a generalized design solution" to address the problems identified by a prior research whilst using design methods to get there. While design research has regularly focused on the development of domain theories and improving design methods, design frameworks, including how design solutions are generated, remain under-developed or at the very least, not well-shared within games literature.

In the remainder of this paper, I present a brief overview of three design research approaches in which design is considered essential in order to characterize its current role. I then present three frameworks that can be useful when thinking through and sharing game-based designs. Neither this review nor the frameworks presented are exhaustive, but are meant to serve as a point for discussion on how to directly address designs and practices associated with game-based education, putting them on equal footing with the learning goals they currently serve.

Three examples of design in research

To contextualize the issue of design in game-based learning, consider three popular approaches to educational technology research in which design plays a central role: design-based research (DBR), design-based implementation research (DBIR), and Instructional Design (ID). Generally, all three approaches address the challenge of creating practical educational interventions that are effective in authentic learning settings (e.g. classrooms) and that simultaneously produce rigorous research.

Design-based research incorporates work from both Brown (1992) & Collins (1992), fully embracing the messiness of authentic settings and the valuable feedback that the classroom contexts can generate. Rather than attempting to isolate variables for later laboratory testing, however, DBR tends to use a process of iterative, theory-informed design to generate claims that can be applied to other contexts, to better understand the context of the intervention's enactment, and to produce demonstrable learning gains at the site of the intervention (Barab & Squire, 2004). Over the past decade, design based research has begun to find stronger footholds internationally, and has developed from a philosophical stance into a productive research approach.

Similar to design-based research is design-based implementation research (DBIR) (Penuel et al., 2011). DBIR has four key elements:

- A focus on persistent problems of practice from multiple stakeholders' perspectives
- A commitment to iterative, collaborative design,
- A concern with developing theory related to both classroom learning and implementation through systematic inquiry
- A concern with developing capacity for sustaining change in systems (p. 332, Penuel et al., 2011).

DBIR, similar to DBR, uses design to augment research practices in order to advance theory and to achieve effective, practical interventions. A key distinction between the two comes from DBIR's extension of "what works" to "when, how, and for whom?" (p. 335, Penuel et al. 2011), and its focus on integrating effective interventions into on-going practices, settings and cultures in order to achieve long-last systemic change.

Finally, instructional design has, since the late 1980s, drawn explicit attention to the intersection of educational practice and theory, teachers and researchers, though an orientation toward design. Reigeluth (Reigeluth, 1999) describes ID as composed of *situations* under which designs can and cannot be applied and the *methods* by which designs can be implemented. To describe the situations, Reigeluth proposes identifying the conditions of instruction (e.g. who is the learner) and the desired learning outcomes (e.g. how effective is it). Methods include how to perform the intervention (e.g. pedagogy), as well as the parameters of the artifact itself (e.g. it should be realistic). Together, the components of ID provide the designed methods of instruction and the conditions under which they should be applied.

Design as peripheral versus design as a focus

The goals of DBR, DBIR, and ID include gathering evidence for learning, defining theories that relate the designs to the learning outcomes, prescribing how designs should be used, and for DBIR in particular, how the intervention can effect systemic change. These approaches can be seen as responses to Collins' (1992) call to apply design science to education. At the time, Collins argued, education technology research and development faced major shortcomings, including a tendency to use technology developments that were atheoretical and to

over-emphasize the potentially biased examination of whether these technologies could produce significant gains in learning. At the same time as Collins' work, Brown (1992) identified what she saw as major challenges to current educational research approaches, emphasizing the tension between complex, spontaneous, and difficult to control classroom learning with laboratory-centric investigations, where isolating variables is taken for granted. For Brown, research that moves between the classroom and the laboratory provides the best of both worlds, allowing for the identification of learning variables in situ, coupling testing in tightly controlled settings with a study of their effects in authentic, real-world contexts.

Despite the way that design is a common factor amongst the reviewed research approaches, it has not in and of itself, been the focus. Instead, the approaches are "design-oriented" (p 12, Reigeluth, 1999) or use design "as an approach" (p 331 Penuel et al. 2011) in order to achieve their other outcomes. This reflects a view of design as a means for theory testing (Cobb et al., 2001), where a researcher takes previously developed theories or hypotheses and instantiates them as a design in order to test them. Design, generally, is a means to an end. In some cases the end is an improved understanding of the strengths and limitations of the *theory* or *hypothesis* in question while in others it's some resolution of a local, meaningful issue (e.g. Penuel et al. 2011). Regardless, design is *used* in design research, not the purpose of it. Being a means to an end does not exempt design from critical examination or theorization.

Approaches that treat designs as instantiations of (and pursuant to) particular theories are problematic for two reasons. First, they treat design as overly rational, instead of considering what's designed is an imperfect instantiation of a theory at best and a lethal mutation at worst. Designs are the products of their contexts, or accumulations of real-world development processes including hundreds of decisions about procedure, the problem that is being solved, and the way the solution is addressed through the design (Edelson, 2002). In other words, design does only address the configuration of the artifact, but is the process that produces it. As an alternative to the rational approach, Schon (1984) describes this process as reflection-in-action, in which designers draw connections between the immediate design problem and their own prior experiences, relying on repertoires of design they have built up through professional practice or experiences. By drawing connections between prior work and the problem at hand, designers frame the problem so that it is familiar and understandable. And while the designer seeks similarities between the current design and prior work in order to propose solutions, the conditions of the world "talk back" to the designer, triggering a re-framing of the problem based on evolving constraints that the design must meet, including differences between the current and prior situations. When a problem is well-defined, generating design solutions means meeting the initial constraints of the project, but when working in an ill-defined problem space, the designer must actively identify the similarities and differences between the current design and prior work in order to evaluate potential solutions' relevance or applicability.

Schon's definition of design as a relational and active process is not the authoritative definition of design, but is useful in highlighting what's missing from current approaches. In particular, designs are often conveyed in terms of principles or heuristics that are overly focused on intent or method. For example, Edelson cites van der akker's (1999) use of heuristics to convey design principles in the form:

"If you want to design intervention X [for the purpose/function Y in context Z], then you are best advised to give that intervention the characteristics A, B, and C [substantive emphasis], and to do that via procedures K, L, and M [procedural emphasis], because of arguments P, Q, and R." (p. 9, van der akker, 1999)

While heuristics such as these can clearly capture the general character of the design, the logic of the designers, and their recommendations for recreating desired outcomes, they rest on the assumption that design is a direct translation from intent to artefact. Because a reflection-in-action approach considers contingency as a core characteristic of the design process, it suggests a need to develop new ways to communicate design especially conveying how the environment "talks back" to the design. Instead of expressing the characteristics that might be desirable within an artifact and explaining how to directly and logically instantiate them, a design framework might instead try to express the relationship between the artifact and the context as they evolve over time.

Second, placing theory above design rather than alongside it runs counter to recent calls to action in education research (e.g. Bang, Cobb, Jackson, Sorum, & Gutiérrez, 2014; Lave & Hall, 2014). Developing effective educational interventions requires moving beyond measures of treatment effect to the coordination of design and practice amongst researchers and practitioners. Though theory is essential, positive systemic change requires directly addressing the interface between theory and the contexts in which a theory is applied, or in other words directly addressing design.

What to share, how to share it?

As game-based learning evolves from a field that investigates *whether* games are good for learning to *how* games can be good for learning, what's needed is a better understanding of how and why the designed components of the educational game came about, especially with regards to the intended and unintended components as well as the conditions of development and use. Design-research approaches are perhaps the current best approach for tackling this problem and warrant what Anderson & Shattuck (2012) describe as a "cautious optimism" in their ability to generate testable theories and practical designs that can be used to improve learning using methods such as iterative development and user testing. As a method, design based research is useful, particularly for its role in theory generation and testing, but there is also a growing need to improve the community's knowledge about how to design good educational games, the varying qualities of these designs, the processes involved in making them, and their use in context.

What's missing in games research, as well as in education technology design generally I argue, is a focus on conveying and improving the theories that explain how we conceptualize design and the practices associated with how we carry it out. What's needed are new ways of sharing design so that other researchers or education practitioners can adapt the design to other conditions and in so doing, improve our understanding of which components are locally contingent and which are generally applicable (Hoadley, 2002). Current approaches that produce "design principles" or recommend including affordance X in game Y to elicit learning gain Z are insufficient for conveying the messy practices and processes that are inherent to design. Theories of design like reflection-in-action provide some advancement in these regards, and suggest ways to frame what should be done, theorized, and shared when conducting design research that incorporate the relational aspect of design. There are of course, other approaches to developing and sharing frameworks that enable the systematic testing and replication of game designs and the following section outlines one alternative, the social infrastructure framework.

Educational games that are not accompanied by an associated theory of learning and design may generate findings that are difficult to replicate, generalize, or otherwise apply to other contexts. At the same time, games that address learning without regard for design, including how the game meets pre-defined and newly developed constraints, run the risk of games that aren't used and interventions that aren't used can't improve learning, no matter how large their effect size. Though video games, generally, are impacting many players' lives and may hold potential for improving learning, more work is needed especially in advancing our understanding of how good designs are produced in order to develop educational games that are not only effective, but used daily and widely.

Such a format for sharing educational game design has been absent thus far, especially as compared to the other products of design research, domain theories and design methods. *Domain theories*, typically academic in nature, fall under models of philosophy of science, taking the form for example, of a hypothesis to be tested (group A performs better than group B) or stemming from conjectures about the nature of a thing (e.g. group A is related to group B in some way). These hypotheses or conjectures, in turn, can be further interpreted with respect to some disciplinary paradigm, in which an entire domain may generally adopt some key assumptions/perspectives (Kuhn, 1962). *Design methods*, are similarly well-established, often described in published definitions of design research. For example, Collins, Joseph, & Bielaczyc (2004) describe a process of progressive refinement, in which designs are put into real-world contexts in order to see how they work and to generate feedback in order to perform iterative design. Brown's design experiments have as a hallmark, a process or method for moving between authentic classroom settings and controlled laboratory environments in order to ensure the effectiveness of the intervention and isolate key variables. *Design frameworks*, unlike domain theories and design methods, have not yet been, at least in educational game research, extensively discussed or clearly detailed and thus far prior work has not been particularly useful in presenting designs.

Though the role of design and its relationship to learning may vary depending on the aims of the research, what remains consistent across research design perspectives is the commitment to basing designs on feedback from real-world contexts in order to generate theory that can be applied to future designs and their use in context. Even approaches that use design as a means for theory testing take into consideration the importance of the interaction between the design and its use in context. Despite its importance, design knowledge is difficult to share, and has tended to either convey abstract principles that are difficult to put into use, or concrete decisions that are context-dependent and difficult to generalize. This is due in part because of the way that design includes both deliberate decision processes and the confluence of contextual factors in which the design process unfolded. Design includes considerations of the tool itself as well as its adaptation to local constraints, not all of which are immediately apparent. Improving design means conveying and improving upon how we share and address both of these design components, regardless of the role of design in research, as a learning intervention's success depends on its design. While determining whether learning has occurred over the course

of a game-based intervention is important, understanding why or how particular designs effect learning and how designs can be recreated in other contexts remains necessary for the field to test and advance theory and to create interventions that can be supported and scaled.

A framework for design: Social infrastructure

Bielaczyc (2006) outlines four dimensions of classroom structures that can be designed: the cultural beliefs dimension, the practices dimension, the socio-techno-spatial relations dimension, and the interaction with the "outside world" dimension. The beliefs dimension includes the way that teachers and students think about learning and knowing, their identities, and the purpose of the tools or technology being used. The practices dimension includes students' and teachers' activities including both what they do with the tool and without it, as well as the social structures of the participants. The socio-techno-spatial relations dimension refers to relationship between the physical and cyberspace as well as the configurations of the students, teachers, and tools within. Finally the interaction dimension considers the way that knowledge is brought into the activity, produced by the activity and consumed by others, and the way that students interact with others.

These dimensions help characterize the aspects of classroom learning that are amenable to design and identify the variables that are important for effectively integrating learning technologies. For example, to show its usefulness, Bielaczyc (2006) analyzes an already-completed study using the social infrastructure framework to identify the participant structures that were described but not previously connected to the way that they contributed to the successful design of a digital collaborative learning activity.

The social infrastructure framework contributes significantly to design research by identifying dimensions that should be critically examined when designing interventions and assessing learning outcomes. Additionally, the dimensions of the social infrastructure framework can also be combined with *implementation paths* or descriptions of the trajectories that teachers go through when adopting new learning technologies, providing a more complete view of a new tool's use. The framework's dimensions however, do not address the dynamic relationship between the dimensions and the design, including its character and what can be done to change it. It is a useful tool presuming the researcher knows how to design well already.

Design as narrative

Similar to the notion of implementation paths is Hoadley's (2002) *design narrative*. Design narratives are characterized by their presentation of a plot that describes and relates the important development events as they unfold over time in a particular setting. Still, for narratives, the challenge is in identifying the components of design that are important enough to convey, as generating design based research results that are credible is a core issue of DBR generally (Barab & Squire, 2005). Narratives, though they address the need to provide details about the contingency associated with the design process, are inadequate on their own in reflecting back on the process itself – once complete, how does one improve or expand upon the design that was just developed and how do we get better at reflecting-in-action?

Where things went wrong

Though educational video games have been around for as long as their non-educational counterparts, they have yet to see the same rates of adoption or impact. This is, in part, due to the way that research has focused on establishing evidence that games produce learning, for example by 1) measuring learning gains produced through game play, 2) comparing game and non-game conditions, or 3) studying examples game-based learning in authentic gaming environments and linking the results of these studies back to the games' design. This research agenda is important in that it provides the political will for supporting the use of games for learning. At the same time, the focus on learning has made it difficult to advance design theory or the outcomes of design. To address these shortcomings, it may be useful to begin considering how we might better communicate projects, both in terms of their learning outcomes, but also in terms of their failures.

That is, design can be considered a process of "proactive failure analysis," in which identifying how a design *fails* (or is perceived to fail) is the first step for improving it. Not reporting failures inhibits design improvements by preventing others from understanding what needs to be "fixed." Additionally, characteristics of design will inevitably differ across projects or fields, and the qualities that lead to success in one classroom may be exactly the same qualities that cause failure in another. Exposing failure, connecting it to design, and explaining context will contribute to the development of design frameworks by providing the opportunity for other designers to understand what happened and to propose alternative solutions.

Finally, considering we as researchers are not the only parties invested in educational design projects, and describing what we consider to be failures may be overly narrow if it discounts other stakeholders in the project. As Petroski (2008) writes "Maker and user, let alone middle man, can have different expectations of

what constitutes acceptable performance (p. 106)" Addressing failure means addressing what all of the participating parties deem as areas of design improvement, as successful research design may not necessarily result in successful teaching design. If we expect the technologies that we create will be used and valued by students and teachers alike, considering failure may help to democratize the design process by including the voices of other project stakeholders.

To game design and beyond

Games are not designed equally, and advancing "good" design is important (Gee, 2003). Game-based learning research has tended to leave readers guessing about how or why particular designs came about, however, making it difficult to establish what good design is or how to do it. It's possible that this neglect may be easily rectified, as there are many theories and approaches to design that may be applicable to educational games. For example, the field of instructional design has a long history of attending to the design of educational technology and educational environments more generally (Gagne, 1981), and organizational management has theorized the role of technology as mediator within an organization (Orlikowski, Yates, Okamura, & Fujimoto, 1995). Finding common ground with educational games, fields who theorize design and applying contemporary, relational theories of learning, will likely be productive. Regardless of which fields' cross-pollination produces fruit, addressing the literature gap in the design of educational games is the first step in designing for lasting positive systemic impact. This paper specifies further steps for community action, calling for a discussion of how we may better communicate and clarify relevant 1) design theories and definitions, 2) design success and who gets to define what counts as success and 3) design failures, including what went wrong and why.

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Resource Usage in Online Courses: Analyzing Learner's Active and Passive Participation Patterns

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Abstract: The paper analyzes the experience with an open university course for a very heterogeneous target group in which MOOC-like materials and activities were used. The course was conducted in a specifically prepared and extended Moodle environment. The analysis involves questionnaires as well as performance data that reflect the resource access on the learning platform. A special focus is put on the participants' acceptance and usage of student-generated versus teacher-provided learning content. Network analysis techniques have been used to identify "interest clusters" of students around certain resources.

Keywords: large online courses, learning analytics, student-generated content

Introduction

Massive Open Online Courses (MOOCs) have become popular especially in the US with powerful providers and platforms hosting a large variety of courses (e.g., EdX, Coursera, Udacity). A famous example of European origin is M. Odersky's SCALA Programming MOOC originally offered by EPFL Lausanne and now also available on Coursera. Since many MOOCs are offered by prestigious institutions, yet open for participation without specific prerequisites and fees they accumulate huge world-wide participation. MOOCs suffer from high drop-out rates, and it is still difficult to turn successful participation in a MOCC into "convertible currency" in terms of accepted credits. Still, MOOCs are a promising innovation of in university education since they explore the potential of massification as a resource for learning and are striving for making online learning more interactive. Because of their independence of location and time (Kay, Reimann, Diebold, & Kummerfeld, 2013), MOOCs are also attractive for heterogeneous groups from an inclusion perspective, e.g. for participants with special needs due to non-standard perceptual or language proficiencies and they might offer a better compatibility of family and studies and/or work with benefits for both students and lecturers.

While MOOCs provide an immense potential allowing people a more independent way of learning, instructors and designers of these environments are confronted with a number of challenges regarding the diverse background of students. Learning materials have to be thoroughly conceptualized in order to meet individual needs of a large group of students with different backgrounds. Moreover, since learning can be understood as an inherently social process (e.g. Stahl, 2000), another challenge of these comparably anonymous formats might be to encourage participants to login week after week, and find tasks allowing and motivating collaboration with other participants.

Goals and research questions

In this paper, we concentrate on examining patterns and preferences regarding the usage of learning materials typical for MOOCs in an online university course with a heterogeneous target group. Current research shows dependencies between the usage of learning management systems and archived learning outcomes (e.g. Mödritscher, Andergassen, & Neumann, 2013). In Germany, many study programmes do not only comprise subject-specific courses, but also demand several courses from other subject areas ("optional studies") with the idea to broaden the students' horizons and to foster cross-disciplinary communication. The selected online course (see next section) was offered as "optional study" course targeting students from various study programmes of two large German universities. Accordingly, our target group was particularly heterogeneous regarding prior knowledge and interests.

Using log data from the platform in which the online course was conducted as well as information gained from several questionnaires that were administered during the course we use different methods to analyze the following research questions that we consider important for online courses in general:

- Are there typical usage patterns or preferences regarding learner-generated vs. instructor-generated content?
- Can success predictors be inferred from resource usage?
- Are there characteristic observable differences between students with a prevalent extrinsic motivation (compliance to get credits) versus intrinsically motivated students?

Context and background

Between October 2013 and January 2014 the online course was accessible for eleven weeks and especially advertised for students at two large German universities who could gain credits for participating actively in the course and passing the final exam. Altogether 162 students enrolled in the course.

The course dealt with psychological foundations of computer-mediated communication (cmc) with a special focus on learning and teaching, covering classical theories of cmc to understand the changes that (might) occur by this mediation as compared to face-to-face settings. In doing so, students were provided with hands-on experiences, e.g. in terms of virtual collaborations in small groups of students working on one specific assignment.

This course was open to a large audience of students in two big universities (>30.000 students each) and completely delivered online, but it was not advertised to the outside. Also, the examination was handled inside the two universities in such a way as to obtain "real" credits. Accordingly, this course was not a typical MOOC in terms of targeting a huge, heterogeneous group of learners with different academic and non-academic backgrounds and age levels. Still, it addressed students from very diverse fields such as business administration, education, or media studies. Apart from the target group, the course integrated several elements and activities typical of MOOCs such as instructional videos, discussion forums, weekly assignments and quizzes.

Upon registration to the Moodle-based course environment, participants were informed about organizational conditions and requirements for successful completion. The choice of Moodle (www.moodle.org) as a learning management system was based on the fact that it was already known to most of the potential participants. Also, we could benefit from a number of dedicated extensions (e.g., a video plug-in) that had been developed in a student software development project on beforehand. Course participants were told to access the course environment regularly and not to be absent for more than two subsequent weeks (otherwise they would be automatically excluded from the course). Moreover, they were informed that they would regularly get the chance to complete questionnaires to assess their course experience in order to improve the course. The weekly learning material provided consisted of a video (6 to 9 minutes in length), in which one of the course organizers contextualized the content and introduced the new material and tasks that could be accessed and downloaded. Besides the videos, one or two texts a week, preferably in German language, were provided as core material, as well as some additional material (e.g. video links and text documents) that could optionally be used as "outside the box" material. Also, the completion of quizzes and individual assignments were part of the required activities. A special format we wanted to test, that differs from most conventional MOOCs (e.g. in the sense of time independence), are collaboration tasks. People had to complete two out of three of these tasks in which they worked in a group of up to four students for one week. In the last week of the course, a wiki for exam preparation was provided, in which the participants could bring together their information on the topics addressed in the course. For the optional studies students, the written examination directly followed after the end of the lecture period.

Overall, our course setting is comparable to MOOC conditions with respect to the voluntary (optional) participation, the heterogeneity of the community (no common prerequisites), and the different materials and learning activities offered. However, the course was not really open to the outside and not particularly "massive".

Learning resource-centered learning analytics

In addition to statistical techniques, our analysis and evaluation of the course activities makes use of computational analysis techniques. Concerning the nature of the input data, such learning analytics methods can be categorized as content analysis, sequence analysis and structural analysis. This categorization naturally applies to the structuring of existing methods for learning resource related analysis in online courses. Content analysis is mostly concerned with the identification and visualization of patterns in possibly collaboratively learner generated artefacts (Southavilay, Yacef, Reimann, & Calvo, 2013) as well as discourse analysis of online discussions (De Wever, Schellens, Valcke, & Van Keer, 2006). While the temporal order in which resources are used by students is of particular importance for sequential methods in order to identify sequential patterns of resource access (Perera, Kay, Koprinska, Yacef, & Zaiane, 2009) or frequent learning paths (Bannert, Reimann,

& Sonnenberg, 2014), structural analysis methods can be used to investigate the relations between students and learning resources in general. This also incorporates descriptive statistics. In the work of Nachmias and Segev (2003) it was shown that nearly all learning resources provided in online learning environments are used by at least one student while the concrete collections of resources used by individuals can differ significantly. In this sense it has been argued that different learner types vary in their preferences for types of learning material provided in online courses (Grünewald, Meinel, Totschnig, & Willems, 2013).

In many cases only the relations between students and learning resources are directly observable from log protocols of the learning resource usage of students. However, relations between resources or students can be inferred indirectly. Association rule mining techniques can be used to discover relations between learning resources that are frequently used in combination (Merceron & Yacef, 2008; Romero, Ventura, & García, 2008). This can be of added value for tutors in order to improve course design.

In the work described in Hecking, Ziebarth, and Hoppe (2014), relations between students and learning resources were represented as bipartite networks in which students are connected to learning resources they used in a certain time period. By applying network analysis methods densely connected clusters of students and learning resources can be identified in those networks. Such clusters comprise a group of students who have a common interest in the corresponding group of learning resources manifested by many connections between the two. By investigating the evolution of the student - resource clusters over time it is possible to discover characteristic resource access patterns in resource intensive online courses. This approach is utilized in this work and will be described in more detail in the Methodology section. The approach of modeling interests of individuals in semantic objects as networks was also used by Harrer, Malzahn, Zeini, and Hoppe (2007) in order to facilitate community building, reflection, as well as trend detection.

In this study we are primarily interested in relationships between students and different types of learning resources. Thus, the applied methods mainly concern structural analyses prior to content and sequential analyses in order to gain generic insights into the role of user generated and tutor provided learning material.

Methodology

Data

Table 1 shows the resource types that were used in the course as well as their goals and tasks. All interactions with the course platform were logged.

Available Resource Type	Goals / Tasks
Video	 Providing an overview of the week's topic
	Teaching selected concepts
	Giving details to the group tasks
Documents (core and optional)	Conveying the learning content
	Basis for group tasks
Quizzes	Self-testing
Forums	• Exchange for group tasks
	• Getting support (questions regarding content and organization)
	Collecting possible exam questions
	• Optional discussion for deepening the knowledge on specific
	topics
Wiki	Summarizing contents for exam preparation

Table 1: Available	resource types	and related goals	/ tasks

In order to analyze the role of student-generated content compared to tutor-provided learning resources from different aspects a triangulation approach comprising different analysis methods was used. In the following, each of the applied methods is introduced.

Resource usage

To get an overview on the general resource usage, the log files accumulated on the Moodle platform were analyzed using descriptive analysis. Furthermore, the Apriori algorithm (Agrawal et al., 1996) has been employed to find rules regarding frequent combinations ("co-occurrences") of learning materials.

Satisfaction with resources and academic motivation

During the course the participants were asked to complete several questionnaires. These contained questions regarding their login behavior as well as their usage of the provided learning material. Additionally, the satisfaction with the learning material was assessed adapting items from Reinhardt (2008) as well as using items from the Training Evaluations Instrument (TEI) by Ritzmann, Hagemann, and Kluge (2014).

Moreover, we were interested in the motivation pattern of participants of this course. We therefore relied upon the concept of the academic self-regulation (Ryan & Connell, 1989). Based on this concept, academic motivation is regarded on a continuum of self-determination (Deci & Ryan, 2002).

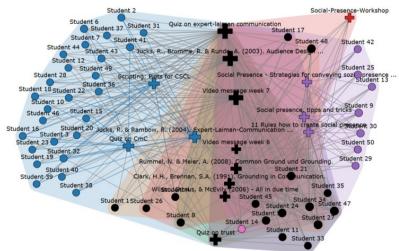
Success predictors

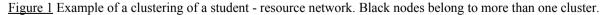
For identification of success predictors linear regression was used. Here, several aspects of student behavior (number of course log-ins three weeks before the exam, views of wiki articles, editing of wiki articles) and their performance during the course (measured via performance in the quizzes) were used as predictors for the final grade in the course as assessed in the final exam.

Student profiles based on resource access patterns

For the modeling of student profiles, the approach of Hecking et al. (2014) was used: Based on the log files bipartite student-learning resource networks were created for each week of the course. Applying the bicliques community clustering algorithm (Lehmann, Schwartz, & Hansen, 2008) partially overlapping clusters of students and resources (as depicted in Figure 1) are identified for each time slice. The students in such a cluster form an interest group because they have affiliations to the same set of resources while not having necessarily social relations. If the similarity of student groups of two clusters in two consecutive lecture weeks exceeds a certain threshold, the group is considered to be the same with two occurrences in the corresponding two weeks. These groups do not necessarily form a bipartite cluster with the same group of resources, which indicates a collective shift of interest. Thus, while clusters are identified for each lecture week an interest group of students during the course are considered to follow a "mainstream" regarding their resource access behavior that is typically influenced by the course design, while there are also students showing more diverse resource access patterns. We define the mainstreaming coefficient (*msc*) for a student *i* who was part of *k_g* interest groups in *k_c* student - resource clusters during the lecture period as: $msc(i) = \exp(\frac{-k_g}{k_c})$.

Students who often appear in clusters, but mostly as part of the same student group, receive high values (close to 1) for msc. For inactive students who were never part of a cluster msc is set to 0.



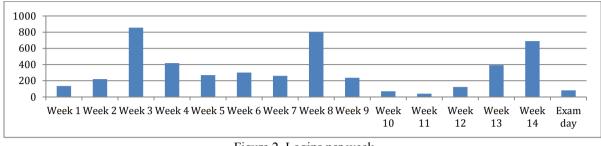


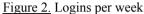
Analysis results

Aggregated resource usage

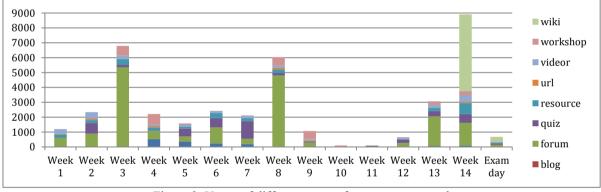
In the following only the log files from the 69 students who took the exam at the end of the course were considered. Figure 2 shows the logins and Figure 3 the usage of different types of resources per week. The activity in week 3 and week 8, in which the first two group tasks took place, was considerably higher than in the

other weeks. In week 13, in which the third and last group tasks was conducted, the amount of activity on the platform was much lower than in the first weeks with group tasks. The most activity in the weeks with group tasks was in the group forums that were provided for group exchange.





After the Christmas break (week 10 and 11), in which the course was paused, the activity increased until the day of the exam. The wiki for exam preparation that was provided in the last week of the course was highly used. 85.5 % of the students taking the exam actively engaged by editing one, two, four of the 11 articles and 79.7 % by writing comments to one to three articles. Every student read at least one article, the average of articles that were read at least once was 9.7 and the median 11 (all); on average each students accessed 47 times a wiki article. The analysis of association rules with the Apriori algorithm based on Moodle sessions shows that wiki articles were mainly opened in the order in which they were arranged on the index page and which corresponds to the order in which the topics occurred in the course (i.e. the articles to the topics of week 1 and 2, week 2 and 3, etc. were often opened together in on session).



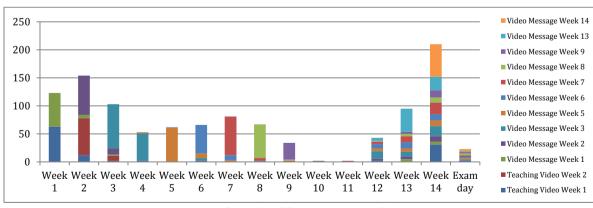


Figure 3. Usage of different types of resources per week

There are indications that exam preparation takes place in the last three weeks before the exam: Although the last quiz was provided in week 7 the usage of the "old" quizzes increased starting in week 12 (see Figure 3). Furthermore, while in the previous weeks the video usage mainly corresponded with the new video

Figure 4. Video usage per week

message provided in that week, the video usage became much more diverse (see Figure 4). Similarly, documents provided earlier in the course are accessed.

Success predictors

To determine the influence of the achieved quiz results during the course (predictor) on the final grade of the course (criterion) a linear regression was used. Results revealed a statistically significant relationship between these two variables, R^2 = .31, F(1,67)= 29.57, p< .001. A negative relationship was found between the achieved quiz results and the grade of the course (β = -.55) indicating that higher quiz grades during the course predict a better final course grade (as lower grades indicate better performance).

Also, the influence of the course views during exam preparation (predictor) on the course grade (criterion) was of interest. Results of a linear regression showed no significant relationship between these two variables, $R^2 = .04$, F(1,67) = 2.96, p = .09.

In order to test whether the passive usage of learner-generated content and the active contribution to learner-generated content can predict the final grade, we calculated two additional regression analyses. First, we used a linear regression to analyze whether the views of learner generated wiki articles predicted the grade of the course. The results showed that the views of wiki articles are a significant predictor of the course grade, R^2 = .16, F(1,67)= 12.43, p< .001 (β = -.40), indicating that the more views of wiki articles are observed the better is the final grade. Moreover, it was of interest if active participation, in the sense of edits on wiki articles, predicted the grade of the course grade, R^2 = .08, F(1,67)= 6.03, p= .02 (β = -.29). Here, also, the more participants contribute actively, the better is their final grade. However, the explanation of variance is considerably lower compared to the passive usage of wiki articles (8% versus 16%).

Satisfaction with resources

Self-reported usage

One set of questions referred to the usage of the learning material provided, i.e. texts, videos, etc.. The largest group (39.7%) reported to have used the majority of the material that was available, 21.9% indicated to have used half of the material, 9.6% claimed to have used all available material and 6.9% reported to have used only minor parts of the material.

Satisfaction with learning resources

The questionnaire also asked for students overall satisfaction with the learning resources provided by the teachers (availability, accessibility, clarity), e.g. "The digital resources that were needed to complete tasks were always provided on time.", "At all times, it was clear which resources belonged to the specific week", "At all times, the purpose of resources provided was clear to me"). Altogether, six items were adapted from Reinhardt (2008) measured on 5-point Likert scales (1=fully agree, 5=do not agree at all; $\alpha = .77$). Overall, results show that people were highly satisfied, M=2.05 (SD=0.73). Satisfaction with resources did not correlate with the final test grade.

Also, items from the Training Evaluations Instrument by Ritzmann et al. (2014) were used for the overall course evaluation. From the instrument that assesses subjective evaluation of the course as well as aspects of the course design (1=does not apply at all, 5=fully applies) the sub-dimensions reported enjoyment, perceived difficulty, knowledge and demonstration were used. The demonstration dimension was based on asking if the learning goals had been clarified and been reached and if the (available) media used were considered helpful and suitable. Internal consistency shows to be good for all sub-dimensions (see Table 2). All means range around the scale mean and show significantly positive correlations with the final test grade (see r-values in Table 2).

Table 2: Means, standard deviation, internal consister	ncy and correlation with final grade for the dimensions
enjoyment, difficulty, knowledge and demonstration	

Dimension	М	SD	α	р	r
Enjoyment	3.12	1.01	.90	.04	.28
Difficulty	3.05	0.76	.74	.03	.30
Knowledge	3.10	0.97	.94	.04	.27
Demonstration	3.10	0.83	.88	.05*	.26

Student profiles based on bipartite clustering

In a further explorative analysis, we have studied contingencies between the mainstreaming coefficient based on the bipartite clustering approach and other variables. This coefficient characterizes a standard, non-deviant behavior regarding the usage of certain resources. Students with a high *msc* have been "flowing the crowd" regarding their interests in terms of resource access. For an overview, Figure 5 depicts the distribution of different interest groups each student belonged to during the course. In order to exclude effects caused by non-active students or students who drop out of the course early, the calculation was restricted to students who were at least part of 5 student - resource clusters during the lecture period. This does not automatically imply that those students were also part of 5 different interest groups. It can be seen that the majority of students belong to less than 3 or less different interest groups but a smaller number has a more diverse resource access behavior, and thus, were allocated to more different clusters.

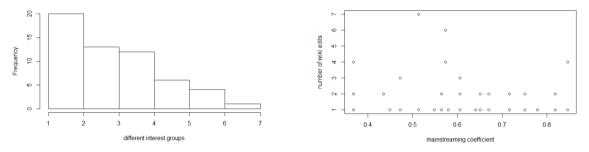


Figure 5. Distribution of the number of different interest groups the students belong to during the course (left) and mainstreaming behavior compared to wiki edits (right).

Mainstreaming often goes along with a high course activity, and accordingly success in the final exam. However, it could not be corroborated that non-mainstreamers performed worse in general. Interestingly, the mainstreaming coefficient is positively correlated with the students' extrinsic motivation (r=0.30, p<.05) as captured by the questionnaires described in the Methods section. This can be explained by the plausible assumption that extrinsically motivated students avoid experimental or explorative behavior because of unclear benefit and likely additional effort.

As the results in the previous section have shown, the exam preparation wiki was used by nearly every student in the week before the exam. However, in total only a small set comprising 44% of all students actively contributed content to the articles while 89% of the editors were students who participated in the exam. Among these content editing students there is a surprisingly high amount of individuals who cannot be classified as mainstreamers. By investigating the number of edits in the exam preparation wiki compared to the mainstreaming coefficient (right part of Figure 5) it can be seen that 50% of the contributors have a mainstreaming coefficient less than 0.61. The comparison of wiki edits and the mainstreaming coefficient of the students suggests that the resource access behavior of students during the lecture do not necessarily have an effect on wiki editing close to the exam. Moreover, student-generated content seems to be important also for some students who were less active or who used learning resources in a more individual way in the weeks before. One possible explanation could be that these students use the wiki to verify their knowledge by presenting it to the community for discussion.

Conclusion

In general, most of the students (the "mainstream") access all mandatory material and stick to the sequence of the course (they access the videos, documents and quizzes in the week they are provided). In the exam preparation phase which starts approximately three weeks before the exam also many resources of the previous weeks are accessed. The activity on the platform increases in this time until the exam takes place. Students were in general very satisfied with the teacher provided course material. While their satisfaction does not correlate with the final test grade, the reported enjoyment, perceived difficulty, knowledge and demonstration correlate significantly. But also the resource usage has some impact: The quiz grades during the course are a positive predictor for the final exam grade. Overall, our aggregated data analysis also corroborates the assumption that students make productive and successful use of peer-generated content. The different analysis results highlight the importance of the wiki for exam preparation: Although the participation was optional and no external motivation like bonus points was provided, most (ca. 86 %) of the students participating in the exam engaged

actively in collaboratively creating a common knowledge base. Not only "mainstreaming" students who were very active during the course participated, but also students who were less active or who used learning resources in a more individual way in the weeks before. While active participation is a weak predictor for the grades in the exam, "passive" reading of the learner-generated wiki articles is a stronger predictor. This indicates that the collaboratively created and edited wiki articles were of high quality and well trusted by the students.

In spite of these encouraging findings, we have to bear in mind that resource access data do not tell a complete story of user behavior. The actual communication and collaboration activities might happen largely off-line and do not appear in the traces that were accessible to us. Nevertheless, the limited perspective on interaction with resources on the platform already allows for relevant insights. Since our results are based on a limited sample of students, the online course will be held and evaluated again in summer term 2015 to also get more fine-grained information on the students' actions (e.g. by click-streams).

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Designing Simple Tools for Socially Shared Regulation: Experiences of Using Google Docs and Mobile SRL Tools in Mathematics Education

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Abstract: The aim of this paper is to describe how simple SRL tools can be used for supporting collaborative learning in the context of a mathematics education course. In particular, we will first introduce the pedagogical design building on a theoretical framework of socially shared regulation of learning (SSRL) and seamless learning. Second, we will introduce simple tools that were used at different points of the collaborative task to increase teacher and student awareness of situation-specific regulation. Third, we will provide case examples to illustrate how the collaborating groups with varying profiles benefit from use of the tool in practice. The results show that highly self-regulating collaborating groups saw the added value of the tool designed to support SSRL. However, the collaborating groups with low levels of self-regulation felt that it was merely an additional tool which needed to "perform".

Keywords: socially shared regulation, regulation tools, web2.0, mathematics, teacher education

Introduction

During recent years, methodological and technological developments in information and communication technologies have changed the ways in which people communicate, collaborate and learn in fundamental ways. Yet merely providing opportunities to use technology is not enough to guarantee deep learning (Järvelä & Hadwin, 2013). Recently, Laru, Naykki, & Järvelä (2014) carried out an analysis of ubiquitous technologies use in educational contexts, and they concluded that more pedagogically grounded instructional design is needed. In particular, effort is needed to put emergent technologies to effective use in promoting learning skills, namely self-regulated learning and collaborative learning, in order to train people with 21st century skills.

Personal, portable and wirelessly networked technologies are becoming more prevalent in the lives of learners, while the development of social media has simultaneously led to new ideas about what it means to participate in educational activities. The interplay between Web 2.0 tools and mobile technologies, as well as the interplay between individual and collective activities is setting new challenges for supporting collaborative learning, as teachers have to integrate these new technologies into more or less traditional learning methods, curricula and everyday school life. On a more general level, a major challenge in the technology enhanced learning field is overemphasis on designing tools and instructional activities for sharing and communicating, while the potential role of tools and appropriate instructional design for guiding and supporting learning processes has been virtually ignored (Järvelä & Hadwin, 2013).

More recently researchers have started to explore how mobile devices, social media or personal learning environments can support or promote self-regulated learning (Kitsantas & Dabbagh, 2011). In a continuation of these research efforts Laru & Järvelä (2014) have developed a pedagogical framework for seamless learning based on the levels of interactivity and self-regulation of learning that different tools and activities enable. The pedagogical framework bridges the gaps between individual and collaborative activities as well as face-to-face and mobile social media activities. The ultimate aim is to promote active learning by facilitating interaction and sharing for engaged learning (Järvelä & Renninger, 2014). Recently, Järvelä et al. (2014) introduced design principles for CSCL tools, enhancing socially shared regulation of learning in collaborative groups. The current paper is based on these theoretical ideas and is a part of larger research project named PROSPECTS (Investigating and Promoting Individual and Socially Shared Regulation of Learning in Primary School and Teacher Education Contexts) (See e.g. Järvelä et al., 2014). In the PROSPECTS project one of the objectives has been to study how to support teacher education on students' effective regulation of learning with regulation tools, during collaborative learning. One of the guidelines in the project is that various forms of technology can be used to increase students' awareness of their regulatory processes and stimulate their cognitive, motivation, and emotion regulation to better achieve their learning goals (Järvelä et al., 2014; Järvenoja & Järvelä, 2009). Furthermore, by harnessing technology to support self and socially shared

regulation of learning, the technology can be channeled to scaffold learners' regulation processes and help students to understand how they learn (Järvelä et al., 2014).

Aim

The aim of this paper is to describe how simple SRL tools can be used to support collaborative learning in the context of a mathematics education course. In particular, we will first introduce the pedagogical design, building on our earlier empirical research and the theoretical framework of SSRL (Hadwin, Järvelä, & Miller, 2011) and seamless learning (Laru & Järvelä, 2014). Second, we will introduce the simple tools which were used at different points of the collaborative task to increase teacher and student awareness of situation-specific regulation. Third, we will provide case examples to illustrate how the collaborating groups benefit from the tool use in practice. These case examples were selected for analysis using extreme case sampling. The idea of extreme case sampling is to select information-rich cases that could increase the depth of understanding rather than providing empirical generalizations (Patton, 2002).

Theoretical background

Regulated learning involves effective strategy use in order to regulate aspects of learning individually, with peers and among groups (Järvelä & Hadwin, 2014; Winne, Hadwin, & Perry, 2011). Successful learners use a repertoire of strategies—cognitive, behavioral and motivational—to guide and enhance their learning processes while completing academic tasks (Schunk & Zimmerman, 2008). It is often assumed that once students have a good basic understanding of relevant strategies, they are all set, but this is not the case. Many students are not able to apply effective learning strategies when they are needed, and thus give up in the face of difficulty (Winne & Jamieson-Noel, 2002). In other words, those students who cannot realize adaptive regulation fail (Boekaerts & Corno, 2005).

Recently, in research on self-regulated learning (SRL), there has been an ongoing discussion about the social aspects of SRL. Earlier mainstream SRL models focused heavily on the *individuals as regulators* of behavior and examined how social context plays a role in the generation of cognition and the pursuit of personal goals (Boekaerts, Pintrich, & Zeidner, 2000). The model suggests that even if SRL can be assisted by external modeling and feedback, it develops within each individual. Another approach is to frame regulation process by using the notion of shared cognition and recent research on collaborative learning (Järvelä & Hadwin, 2014). The idea is, in essence, that shared understanding is co-constructed (Roschelle & Teasley, 1995), and thus requires collective regulation, in which groups develop a shared metacognitive awareness of goals, progress, and tasks, thereby *sharing regulation* processes as a collective (A. Hadwin & Oshige, 2011; Järvelä & Järvenoja, 2011).

Methods and participants

This study followed the principles of the design based research (DBR) method (Brown, 1992), and by approaching the research from design-based research perspective the aim was to conduct design and pedagogical interventions in formal educational settings and to study the effect of the interventions on learning events. Mixed methods have been employed, such as qualitative analysis of data gathered from mathematics education lessons, collaborative group work and analyses of the server logs generated by the use mobile SRL apps and other tools.

Participants and context

The participants were 44 undergraduate students (36 females and 8 males, mean age 24.9 years) enrolled on a five-year primary teacher education program at the Faculty of Education at a Finnish university. All of the students were enrolled on a compulsory course titled "Mathematics education, part II" during the spring semester of 2014. The participants worked in groups of three to four students for 8 weeks. Groups were divided into high, mixed and low regulators based on their individual scores in the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich, Smith, Garcia, & Mckeachie, 1993). The pedagogical design of the mathematics education course consisted of lessons and collaborative group tasks. Each of the lessons involved a small collaborative group task. The students worked in the same four-member groups to complete both the lecture assignments and the course assignment. All together there were eleven collaborative groups. Both lessons and group tasks took place at the LeaForum interaction laboratory, which is a versatile teaching and observation facility equipped with various modern devices (internet tablets, interactive video projectors etc.) and flexible fittings to provide for different group compositions.

Pedagogical design for socially shared regulation of learning

In the context of the mathematics education course, a prototype regulation tool (S-REG) and Google Docs were used as learning tools, and tablet computers as devices during the lessons and collaborative tasks (see Figure 1). Students were offered guidance for using the S-REG regulation tool and Google Docs. In order to introduce the main principles of self-regulated learning at the start of the math lessons a short newsflash was given at the beginning of every lesson.

- 1. Mathematics education lesson (8 x 2 hr mathematics education topics): (see also Figure 1)
 - A. *News flash* [coaching in self-regulated learning]: In this phase different SRL topics were introduced to the students
 - B. *Grounding* [introduction to the topic]: Each of the eight course weeks started with an introduction to a topic, in which students were grounded in main concepts related to mathematics education. The specific themes were in the following order: 1) introduction to the course, 2) approximation and mental calculation 3) teaching percentages 4) assessment and evaluation 5) problem solving 6) teaching algebra 7 and 8) coursework presentations.
 - C. *Regulation phase* [increasing awareness of regulation]. Students used the S-REG tool to increase awareness of their regulatory processes and stimulate their cognitive, motivational, and emotional regulation to better achieve their learning goals.
 - D. *Collaborative problem solving* [transferring knowledge to practice]. In this phase aim was to transfer mathematical knowledge to practice by solving problems connected to the lesson's topics in working groups.
- 2. **Coursework** (5 x 3 hr): Create a mid-term plan for mathematics:

The groups were required to design a mid-term plan in the form of a Google Docs document by the end of the semester. Topics for the mid-term plans were: Numbers and calculations for the 6th grade (12–13-year-olds), Primary algebra and functions for the 5th grade (11–12-year-olds), Data processing and statistics for the 6th grade, Geometry and measurement for the 4th grade (10–11-year-olds), Numbers and calculations for the 4th grade. The students chose more refined topic from these larger topics. In order to complete mid-term plan project, the students needed to write two documents: a planning document and a mid-term plan document. The mid-term plan consisted of six sections: 1) Introduction and theoretical framework, 2) Aims of the plan and description of how the school curricula will be used in the plan 3) Evaluation of learning materials 4) Assessment plan 5) Planned lessons 6) Bibliography. The pedagogical design of the group task was as follows: (see also Figure 1)

- A. *Planning phase* [promote SSRL and keep track of the process]: In the first meeting groups created socially shared planning document (described in the tools section). This plan was revised a) after problems with group work and b) at the beginning of each collaborative group workshop
- B. *Regulation phase:* [increase awareness of regulation]. Students used the mobile regulation tool to increase their awareness of their own regulatory processes and stimulate their cognitive, motivational, and emotional regulation to better achieve their learning goals
- C. *Execution phase*: [task execution] in this phase the student groups did their group work: a mid-term plan for mathematics education.
- D. *Problem phase* (if any): If students had any problems with their task execution they were advised to carry out phases A and B again and then continue their task execution.
- E. *Execution phase* (continues after the problem phase and phases A and B): [task execution] in this phase the student groups concentrated on their group work: a mid-term plan for mathematics education.

Tools to support socially shared regulation of learning

In this study the design of the S-REG tool and the Google Docs planning template followed three design principles for supporting SSRL (as presented in Järvelä et. al (2014)): awareness, externalization and promoting regulation. The design of the S-REG tool and the use of Google Docs as a planning tool reflect experiences gained in the first design cycle where the VCRI tool was used to support SSRL activities.

Google Docs as socially shared planning tool. The collaborative task included a planning phase (see Figure 1) in which group members created (new plan) or revised (existing plan). In this phase the group

members used a Google Docs template (see table 1) which prompted groups to identify and develop SSRL strategies (Järvelä et. al, 2014).

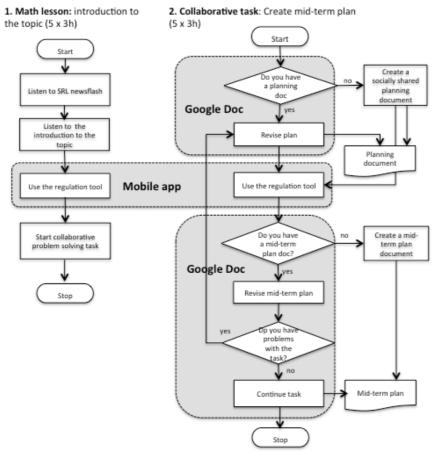


Figure 1. Task flow during the course. Left: Math lesson. Right: Collaborative group task

Table 1: Questions in the s	ocially shared planning	g document template tool

#	Primary question in template	Theory
1	Describe the topic and the structure of your mid-term plan	Task understanding
2	What issues do you need to consider for planning your mid-term plan?	Task understanding
3	How you will structure your work? What concrete steps and targets will you use?	Planning and goal setting
4	How you will organize your work?	Strategy use
#	Additional questions in the template	
1	How challenging does your group think this task is? Explain why?	Internal task conditions
2	What is your goal for this group work exercise?	Goal setting
3	How are you going to work as a group to achieve this goal?	Strategy for collaboration

The S-REG mobile web app is a simple and responsive HTML5 application which was designed to run on smartphones, tablets and desktops, unlike the VCRI tool, which was limited to desktop computers running Microsoft Windows. S-REG uses Google API for Oauth 2.0 authorization. In practice students were provided with a seamless user experience, with Google Docs used for planning and S-REG for supporting individual group members' awareness; externalization of motivational, emotional and cognitive aspects; and prompting groups' socially shared regulation. Both task types (mathematics lesson and collaborative task) included a phase(s) (see Figure 1) in which the regulation tool was used to support SSRL. The activity flow when using S-REG consists of five sections, which were shown to individual students after all group members had completed their respective activities in the current section (see Table 2).



<u>Figure 2.</u> Left: Recognition of cognition/emotional/motivational status, Middle: Synthesis of group members' responses, Right: Pre-stocked options for targeted regulation

Table 2. User	interface	sections	of the	regulation tool

Section	User interface component(s)	Definition for component	Level	Phase
Frontpage	User login, task selection	User and context identification	Individu al	-
Individual status	Three rounded sliders (cognition/motivation/emotion)	Recognition of cognition/motivation/emotion	Individu al	Self-awareness
Group status	Three color indicators (available colors: red, yellow, green)	Synthesis of group members responses [If lowest between 0–33 then red If lowest between 34–66 then yellow If all 67–100 then green]	Group	Group-awareness
Group prompt	Image: two persons talking	Discussion – What is the reason for your group color?	Group	Reflection
Action Pre-define options for the prompt targeted regulation		When the color is red or yellow there will be a list of options to label the main reason coming up in a group discussion. When the color is green there will be an open space to specify the reason.	Group	Reflection
Action prompt	Regulation prompt	Targeted feedback about regulation possibilities	Group	Adaptation of appropriate Regulation

Data collection

The data consists of self-reported data (i.e. questionnaires and interviews), time based sampling data (i.e. log data) and the learning results collected in the context of the mathematics course.

- **MSQL questionnaire data from previous design cycle**: Existing MSQL questionnaire data was collected from the students prior the course.
- **Students' products collected for learning assessment**: All products created in student groups were collected not only for research purposes, but also for students' learning assessment. This data consists of two self-evaluation questionnaires, mid-term plans (coursework) and voluntary extra calculations.
- **Interviews conducted after the course**: The interview data consisted of 43 interviews, on average 15–20 minutes, which were conducted at the end of the course.
- Log-files generated by use of the S-REG tool: Use of log-file data produced by the S-REG tool, which included: 1) activity path [students actions within the UI] 2) values entered by subjects: a) session selector [lesson/coursework]; b) rounded SRL-dials [cognition, motivation, emotion]; c) textboxes [explanation for green color]; d) list menu [SRL-prompt chosen from the suggested list of prompts].

Data analysis

- **MSQL data was used for grouping the students**: In the context of this paper MSQL data (which was already processed in an earlier design cycle) was used to choose and contrast a group of low-regulating students against a group of high-regulating students.
- Scoring procedures for the assessment data: The course grade for students s was given using the sum Grade(s) = midterm plan(s) + self-evaluation(s) + voluntary calculations(s). The *Midterm plan* was graded from 0 to 3 by the math teacher. *Self-evaluation* was the students own assessment, dealing with topics such as "I can explain what is the most important issue in teaching percentages? Why?" (this was asked in the questionnaire, using the likert-scale). The *math calculation* was a voluntary task which was graded as either pass or fail (this task dealt with the topics presented during the lectures).
- **Log-files:** Log-file data was exported from the S-REG tool in Excel-format. Although the log-files had fine-grained data about individual students' actions, only group level values were calculated for this paper.
- Interviews: The interview data was transcribed and analyzed in order to explore students' opinions on how the S-REG tool supported their learning activities. In the excerpt from the interviews which was used in this paper, students were asked to rate the S-REG tool on a scale of 0–10 and explain how it supported their group during the course.

Results

Assessment and MSQL scores

Assessment and MSQL scores (see table 3) were used to choose and contrast low and high regulating group in the comparison of the usefulness of the S-REG-tool. Based on the results, group B3 was chosen as the low regulating group, because both their course average score and their MSQL average were the lowest on the course. Group A1 was chosen to be the high regulating group because their MSQL average score was highest.

Group	MSQL	Self (avg) [0-2]	Teacher (avg)	Exercise score (avg)	Course score
	(avg)		[0-3]	[0-1]	[0-5(6)]
A1	424	1.8	3	0.3	5
A2	397	2	3	0.5	5.5
A3	360.5	1	3	1	4.8
B1	400.8	1.8	2.3	1	5
B2	355.8	1.5	2.3	1	5
B3	323.3	1.3	2	0.3	3.5
C1	399	1.7	3	0.7	5.3
C2	355	1.8	3	0.5	5.3
C3	346	2	3	0.5	5.5

Table 3: Assessment and MSQL questionnaire average scores at group level

Differences in the synthesis of the cognitive, motivational and emotional states between high and low regulating groups

Table 4 shows the differences in cognition, motivation and motivation between a group of high-regulators (group A1; avg MSQL score 424(24.83)) and a group of low-regulators (group B3; avg MSQL score 323.3(5.74)). The synthesis of group members' responses (collected from the problem solving task in the math lessons) suggests that students who had a low score in the MSQL test also had lower group level cognitive, motivational and emotional values from the S-REG tool. However, as table 4 shows, both groups got yellow or red values each time while they were using the tool.

Table 4: To	pics of mathematics	lessons and group	level values from	the S-REG tool

				Need for			
Group	#	Inspiration Talk Topic	Topic	regulation	Cognition	Motivation	Emotion
A1	1	Tool introduction	First lecture	R+	Red	Yellow	Red
A1	2	Collaborative learning	Approximation & Mental Calculation	R+	Green	Yellow	Yellow
A1	3	Motivation	Teaching percentages	R+	Green	Yellow	Yellow

Group	#	Inspiration Talk Topic	Topic	Need for regulation	Cognition	Motivation	Emotion
A1	4	Emotion	Assessment & evaluation	R-	Green	Green	Yellow
A1	5	Cognition	Problem-solving	R+	Green	Red	Red
A1	6	Wrap up	Algebra	R-	Green	Green	Red
			Average:	R+	Green	Yellow	Yellow
В3	1	Tool introduction	First lecture	R+	Red	Red	Red
B3	2	Collaborative learning	Approximation & Mental Calculation	R+	Red	Red	Red
B3	3	Motivation	Teaching percentages	R+	Green	Yellow	Yellow
B3	4	Emotion	Assessment & evaluation	R+	Yellow	Red	Red
В3	6	Wrap up	Algebra	R+	Green	Red	Red
			Average:	R+	Yellow	Red	Red

Students' opinions about how the use of S-REG tool supported their learning activities

The results from the interviews reveal that students in the high regulating group show the potential of the S-REG tool for supporting socially shared regulation in their activities, but low regulating students felt that it was more of a joke than a useful learning tool.

"My score for the app is 9. It forced us to think about our emotions and intents regarding the task. It forced me to think about my emotions and to regulate the task" (Iris. Group A1, MSQL 417, course grade 5, app evaluation 9)

"Score is 7. It was a bit dull, but it forced us to think and discuss topics that are not normally discussed at all." (Julia, Group A1, MSQL score 416, course grade 5, app evaluation 7)

"Maybe it did support our learning. Maybe not. We already knew each other's emotions, motivations etc. After brief discussions we knew what was going on. I don't think that it supported us." (Aleksi, Group B3, MSQL 326, course grade 4, app score: 8)

"Well it was interesting to know fellow students' feelings. It sometimes made me change my own feelings. But quite often it was just joke, we just filled in the values and then continued with our task. We got bored very quickly" (Juliaana, Group B3, MSQL 315, course grade 2, app evaluation 6).

Members of both groups argued that the S-REG tool was used only at the beginning of the activity, which rendered it quite useless. This finding supports the idea that a change of design to suit learning activities would increase the frequency of tool use.

"I didn't feel that it was important. It was filled just at the beginning of the lesson" (Juliaana, Group B3, MSQL 315, Course grade 2, app evaluation 6)

"My grade for the app is only 7 because it was just used very briefly and rapidly. It was only a quick phase that had to be completed before starting the real tasks" (Julia, Group A1, MSQL score 416, Course grade 5, app evaluation 7)

"Well, it had a lot of good functions, but I felt that it wasn't an interesting application, it was just something to be completed and that's all. But still I want to give 9 because it made me think about emotions and intentions" (Iris. Group A1, MSQL 417, Course grade 5, app evaluation 9)

Discussion

The aim of this paper was to describe how simple SRL tools can be used for supporting collaborative learning in the context of a mathematics education course. First, the pedagogical design presented may help other scientists and educators to create designs for collaborative learning which follow the theoretical framework of SSRL.

Second, the tools used in this study were off-the-shelf social media tools (Google Docs) and simple HTML5 based www-apps (S-REG) which can easily be customized in order to suit different types of pedagogical designs. In this study, these tools were used at different points of the collaborative tasks to increase teacher and student awareness of situation-specific regulation. Earlier research has shown that students who receive support for their regulated learning tend to learn better in comparison to students who do not receive support (Azevedo et al., 2012). However, the results indicate that the students' SRL skills determine the added value of the S-REG tool. Therefore, the importance of pedagogical design is key in enhancing skills for regulated learning.

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Maximizing Benefit of Peer-Feedback to Increase Feedback Uptake in Academic Writing

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Abstract: Revising text is an essential part of the writing process. Yet, inexperienced writers revise their texts too superficially. Peer-feedback has become a popular method to provide elaborate and timely feedback to students during writing. Though peer-feedback has shown promising results, studies also indicate that students have problems benefitting from feedback, resulting in a lack of feedback uptake and little revision. Students might need to be facilitated to make sense of feedback and reflect more deeply on it. The study investigated the effect of sense-making support on revision skills and feedback uptake. Altogether, 73 university students were assigned to a condition either with or without sense-making support. Results showed no effect on revision skills, yet results of content-analysis yielded a significant effect concerning feedback uptake. Students in the condition with sense-making support made less new errors and rejected more incorrect feedback. Sense-making support appeared to help students to some extent to maximize benefit from peer-feedback.

Keywords: peer assessment, feedback uptake, academic writing

Introduction

Writing well is a challenging task for students. One central part of becoming a good writer is to understand the importance of revision. Revision relates to any changes writers make during writing (Fitzgerald, 1987). Engaging in revision practices can have substantial impact on the quality of a written text as well as on learning. During revision writers re-organize ideas, integrate new ideas with existing ones to produce a coherent line of argument (Fitzgerald, 1987). Problem detection and problem correction have been identified as crucial sub-processes for revising a text. During problem detection, gaps are identified between the intended text and the meaning of the text produced so far. During problem correction, the writer needs to decide what should be changed in the text, how to make desired changes and how to instantiate those changes in the text (Flower, Hayes, Carey, Schriver, & Stratman, 1986; Hayes, 2004).

Students' problems to revise texts

Revision is generally a difficult process (Scardamalia, Bereiter, & Steinbach, 1984). Especially inexperienced writers tend to accommodate too little time for revising a text in its draft state (Allal & Chanquoy, 2004) and revise text superficially (Hayes, Flower, Schriver, Stratman, & Carey, 1987; Proske, Narciss, & McNamara, 2010). The first step, detecting a problem is harder for students than for expert writers. Students have a less clear goal in mind representing what the text should convey. Furthermore, students have problems to read their text from the perspective of the reader considering their audience. In addition, students follow less elaborate writing criteria than expert writers (Graham, McArthur, & Fitzgerald, 2007). Yet, to identify a problem or an error, a writer needs to have knowledge about criteria for good writing including knowledge about typical writing errors. The second step, correcting a problem is still challenging even if the problem is detected. Fixing errors is not an automated process for inexperienced writers but a challenge on its own. As students lack those skills that are important for revision, they need help to become aware of problems in the text and need to receive suggestions how to correct the text (Hayes, 2004).

Peer-feedback in academic writing

Peer-feedback has become a popular method in learning. The following activities belong to the overt activities typically included in peer-feedback: First, the assessee creates a product (task performance). Next, it is the assessor's turn to provide feedback (feedback provision). Subsequently, the assessee needs to make sense and form a coherent picture of feedback (feedback reception). Lastly, the assessee revises his or her own product based on feedback by the assessors (revision) (Kollar & Fischer, 2010). Receiving and providing feedback from peers has been shown to be very effective and it has considerable advantages in comparison to feedback from an instructor (e.g., Topping, 1998). Peer-feedback does not only complement instructors' assessment (e.g.,

Hammer, Ronen, & Kohen-Vacs, 2010; Zariski, 1996), it can be also provided more timely and frequently than feedback from an instructor (Falkichov & Goldfinch, 2000). There has been a shift in research on peer-feedback from merely focusing on the reliability and validity aspects towards viewing peer-feedback as a social process. Providing and receiving peer-feedback can be inherently understood as a collaborative activity holding rich learning opportunities for both the assessor and assessee (Falchikov & Goldfinch, 2000).

Especially in courses focusing on writing, peer-feedback can help students become better writers and to gain understanding about subject-matter (Falchikov, 1986; Roscoe & Chi, 2007). During writing, a student receives comments from a peer describing the reader's perspective, pointing out writing errors, making suggestions on how to revise the text. Assessors can help assessees to detect problems, which is a central sub-process for successful revision (Hayes, 2004). Though it is agreed that problem detection is necessary, it is not sufficient for correcting a problem. After a problem is detected, the assessee still needs to decide what to do with the feedback in order to revise effectively. An assessee has various options: Either the feedback is rejected because the problem pointed out is perceived as too trivial or too difficult to correct, resulting in no revision. Or the feedback is considered to be relevant. As a consequence the assessee fixes the detected problem thereby revising the text (Hayes, 2004).

Assessees' problems to leverage from peer-feedback

There is clear evidence that students have problems to leverage from feedback. Students hesitate to use feedback or feedback is rejected upfront without considering the information it contains (Boero & Novarese, 2012). Van der Pol and colleagues (Van der Pol, van den Berg, Admiraal, & Simons, 2008) call this problem a failure of feedback uptake. Feedback uptake is the ability to make use of feedback in such a way that it leads to changes in the text. In other words, feedback uptake relates to revisions that are made based on feedback. For student writers, feedback uptake is important, because without considering feedback, students might struggle to detect errors by themselves. Therefore we believe an important question to ask is: Why do assesses fail to benefit from feedback during writing? Research on peer-feedback indicates several problems that might prevent feedback uptake (e.g. Gennip, Segers, & Tillema, 2010; Nelson & Schunn, 2009).

One problem concerns the limited knowledge how to handle feedback and the information it contains. Students may not know how to use feedback for the purpose of problem correction because as inexperienced writers they do not have a model of how to work through the problems systematically. Expert writers have the ability to represent detected writing problems in a means-ends table that helps to correct problems with a systematic procedure which novice writers are lacking. Doing a means-ends analysis, expert writers have a better understanding what actions need to be taken to correct problems and to successfully revise texts (Hayes, 2004; Newell & Simon, 1972).

Another problem concerns reflection of received feedback. Assessees do not sufficiently engage in reflection on their own. Yet, reflection has been identified as a crucial aspect for the process of acquiring knowledge and new skills (Zimmerman, 1989). During peer-feedback reflection is especially important for students taking the role of the assessee. Reflecting helps assessees to maximize potential benefits from feedback. Reflecting consists of several processes including (1) planning, (2) monitoring and (3) evaluation (Schraw, 1998). Those processes are central for reflecting on feedback. Planning includes understanding one's own knowledge of feedback. This involves that assessee knows how information contained in the feedback (assessors' intentions) relates to the meaning conveyed in the text (assessees' intentions). Monitoring includes keeping track of feedback that is agreed upon and feedback that is rejected. Evaluation includes judging which feedback is rejected and which feedback will be used for improving the text.

Supporting the assessee to benefit from peer-feedback

When integrating peer-feedback in instruction both problems, (1) limited understanding of how to represent problems in a means ends table and (2) lack of reflection on feedback need to be considered. Integrating peerfeedback alone might not be sufficient to ensure feedback uptake. Instructional support might be needed for learners' learners to benefit from peer-feedback to succeed in feedback-uptake. Combining peer-feedback with instructional support might maximize effects of feedback in terms of feedback uptake. Instructional support should tackle the mentioned problems: First, assessees should be facilitated to represent problems as part of a means-ends table. Doing so should help students to represent the relation between detected problems and actions that need to be taken to fix a problem in the text. Second, assessees should be supported to reflect more deeply on feedback. Similarly to learning protocols (Berthold, Nückles, & Renkl, 2007), assessees should write down their reflections on previously presented peer-feedback. Support should instruct the assessee to think about whether the feedback was understood, whether there is a gap between the assessor's intentions and the assessee's intentions, whether feedback is considered to be used and how it will be used to improve the text. In other words, instructional support should encourage the learner to make sense of feedback.

There is substantial evidence that taking the role of the assessor by providing feedback and assessing products created by peers, leads to learning gains (Topping, 2003). Yet, there is little empirical evidence that taking the role of the assessee that is to receive feedback leads to learning gains as well (Van der Pol et al., 2008; Cho & MacArthur, 2010; Kluger & DeNisi, 1996). This study focuses on supporting the assessee. In our study, we explore whether instructional support, in form of sense-making support helps assessees to maximize benefits from feedback. Based on our assumptions, we expected that sense-making support improves assessees' revision skills (Hypothesis 1). Since revision skills were subdivided in problem detection and problem correction, we hypothesized that both sub-skills will improve if sense-making support is provided. Furthermore, we expect that sense-making support will facilitate feedback uptake (Hypothesis 2). Since feedback uptake was conceptualized as changes that assessees make based on received feedback, we assumed that students incorporate more feedback-based revisions in the text.

Study design

Participants

Altogether, 73 students (12 male, 61 female) from a German university participated in the study. Students studying towards a degree in education served as participants. The mean age was 23.37 (SD=3.37). They were enrolled in introductory and advanced courses in education. Participation was an obligatory part of their regular class activities, however no grades were given for the writing activity. Participants were randomly assigned to one of two conditions: Sense-making support condition SMS+ (N= 34) and no-sense-making support condition SMS- (N= 39). Conditions differed only concerning presence of sense-making support.

Learning materials

Students participated in an online writing activity. The task was to write an essay of 550-650 words on the question "How can a mother optimally support the identity formation of her child". As background information, students received an excerpt of a text from Erikson (1984) on identity formation. The task was accompanied by peer-feedback.

Description and implementation of sense-making support (independent variable)

Sense-making support was delivered during feedback-reception in a MS WORD-document. Students in the SMS+ condition were asked to use the document during peer feedback reception. The document included a table with seven columns (see Figure 1). Sense-making support aimed at encouraging participants to reflect on understanding the feedback involving planning, monitoring and evaluation of feedback. The first column was listing each feedback comment (column 1). Students were instructed to list each feedback comment using the copy/paste function. Participants were asked to judge each comment in the list concerning understanding (column 2), agreement (column 3), and impact on text (column 4) and to indicate how the comments will impact their text (column 5), organization (column 6) and relevance (column 7).

1	2	2	3	3		4	5	6	7
Copy your received comments into this column.	received th ments into comm		l understand l agree the with the comment. comment.		l am going to use this comment		I will improve my essay by doing the following:	Done	Mark the three most important comments
	Yes	No	Yes	No	Yes	No		✓	with an X.
Comment 1									

Figure 1. Sense-making support table

Procedure: Online-writing activity with peer-feedback

The online-writing activity was conducted during a period of two weeks (see Figure 2). The learning platform Moodle was customized for the online-writing activity (Moodle, 2013). We followed the structure of the peer-feedback phases identified by Kollar & Fischer (2010) focusing on the role of the assessee.

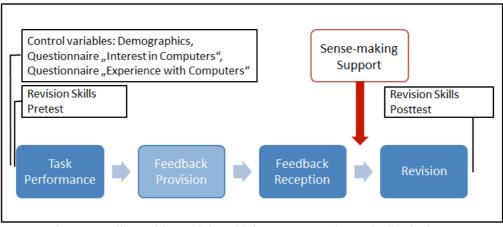


Figure 2. Online-writing activity with instruments and peer-feedback phases

During task performance, students received instruction and background information to write the essay (see Table 1). Students were asked to upload the essay as WORD document. Feedback provision was secluded because all participants received feedback from tutors but they did not provide feedback themselves. During feedback reception, participants received peer-feedback. During revision, the essays including feedback comments were made available and participants revised their essays. Afterwards, participants uploaded their revised documents to Moodle. Participants were guided through each phase on a step by step basis. Each phase became active, when the previous one was completed.

Table 1: Online-writing	activity	^{including}	times for	peer-feedback p	hases

Peer Assessment Phases	Time on task (min)
Task Performance	120
Feedback Reception	10
Revision	80

As described above, all participants took the role of the assessee. Participants were informed that the feedback was given by a peer. However, in order to control for variance of feedback quantity and quality, feedback was given by trained tutors. Peer-feedback included 12 comments for each participant. Each comment referred to one error in the text. It included a standardized description of the error and a suggestion how to revise it (see Figure 3).

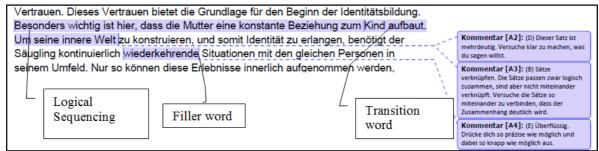


Figure 3. Examples of highlighted comments

Each comment identified one out of 5 writing errors related to Sequence/Logic of Argument, Transition Words, Nested Sentences, Direct/Clear Reference and Filler Words. The content of a comment was structured such as: "This sentence is hard to read. Rephrase it in order to make it more readable". Each student received two comments per writing error (10 comments all together). Additionally, two incorrect comments were included, because peer-feedback is prone to be erroneous. Feedback was given in the WORD documents using the commenting function of MS Word. For each writing error we highlighted the relevant portion of the text. For filler words we highlighted the word itself, for missing transition words we highlighted the last word and the first word of the adjacent sentences. For the remaining criteria we highlighted the whole sentence.

Feedback was provided by trained tutors following a rigorous procedure. First, tutors read an essay in order to get an impression of the intended statement and logical structure of the essay. Next, the essays were reread and commented on focusing on one writing error at a time. Tutors read each essay at least six times. Each error was commented with a standardized comment for each writing error.

Measures and instruments

Control measures and treatment check

We controlled for uneven distribution in the conditions taking into account demographical information, experience with and interest in using computers. In order to see whether sense-making support was used as intended, we analyzed participants' attendance to the sense-making support table.

Revision skill (pre-posttest)

Revision skills were assessed using counterbalanced pre- and posttest versions. The pre- and posttests assessed two distinct skills related to academic writing: problem detection and problem correction. Problem detection was assessed with an erroneous text and participants were asked to highlight and label errors in the text. The maximum score was 20 points. For problem correction, participants had to correct errors in text sections. Errors were related to the writing errors described earlier. The highest score that could be achieved was 22 points.

Feedback uptake

Feedback uptake was assessed by measuring feedback-based changes in the text and correctness of changes after feedback was received. Below, we refer to feedback-based changes, that is, only changes that were made based on received feedback.

Feedback uptake variables	Description	Agreement %	Kappa
Successful change	Any change that resulted in an improvement of the text.	87,3%	.66
New error change	Any change that erroneously created a new mistake instead of correcting one.	91,3%	.47
Incorrect comment change	Any change that was made based on an incorrect feedback comment.	90,1%	.82

Table 2: Description and reliability of feedback uptake variables

All dependent variables were measured at the individual level. For all analyses, coders were unaware of the treatment conditions. 25 % of the texts were coded by a second coder. Coders' percentage of agreement was between 87% and 91% (see Table 2).

Results

Reported results can vary with respect to number of participants, because not all 73 participants finished all relevant stages.

Control measures and treatment check

We controlled for uneven distribution in the conditions taking into account demographical information, experience with and interest in using computers. Participants in both conditions showed no substantial differences regarding prior experience with computers (F (1, 71) = .02, p = .88) and interest in computers (F (1, 71) = .46, p = .50). In order to check whether sense-making support was used as intended, we analyzed participants' attendance to the sense-making support table. We were interested, whether the participants (N=34) attended to each of the columns particularly columns three, five and six.

Out of 10 feedback comments, participants noted to understand 85.9%, agree on 61.8% and use 70.3% feedback comments (see Table 3). For every comment we have also captured whether the particular comment was used or not, therefore we were able to relate the comments that were used to the comments that were reported to be used. We found that participants actually used 93.6% of the comments they indicated to use. Out

of the 2 additional erroneous comments, participants noted to understand 82.5%, agree on 41% and use 47% feedback comments However, they only used 75.5% of the comments they indicated to use. Based on these results, it appears that participants have used sense-making support for the purpose of reflection.

	Feedback comments (10)			Additional erroneous feedback comments (2)		
	М	(SD)	%	М	(SD)	%
Column 3: "I understand the comment"	8.59	(1.84)	85.9	1.65	(.60)	82.5
Column 5: "I agree with the comment"	6.18	(8.57)	61.8	.82	(.80)	41.0
Column 6: "I am going to use the comment"	7.03	(5.85)	70.3	.94	(.78)	47.0
Actual usage of feedback comments for revision	8.0	(1.65)	80.0	.85	(.70)	42.5

Table 3: Means and standard deviations for participants' attendance to sense-making support table

Effect of sense-making support on revision skills

The low number of participants resulted from a combination of corrupted files and participants that did not take part in the last phase of the online activity in which the posttest was conducted. An ANOVA showed no significant differences between both conditions regarding revision skills F(1, 48) = .1.81, p = .18. Descriptively, problem detection scores increased from pre to post in the SMS+ condition, while in the SMS- condition, problems detection scores decreased (see Table 4). Problem correction did not change from pre- to post test.

Table 4. Means and standard deviations for revision skill

	SMS+ (N=20)				SMS- (N=31)			
	Pre		Post		Pre		Post	
	М	(SD)	М	(SD)	М	(SD)	М	(SD)
Problem detection (PD) (max. 20 points)	7,76	(4,023)	8,80	(4,029)	9,54	(3,144)	8,84	(3,284)
Problem correction (PC) (max. 22 points)	16,73	(3,118)	16,19	(3,270)	16,72	(2,976)	16,58	(2,355)
Revision skills (PC+PD)	25,27	(5,423)	24,88	(6,192)	26,72	(4,531)	25,54	(4,207)

Effect of sense-making support on feedback uptake

A one-way multivariate analysis of variance (MANOVA) was conducted to determine the effects of sensemaking support on feedback uptake with the variables successful change (SC), new error change (NC) and incorrect comment change (IC). Results showed a significant effect, Wilks $\lambda = .85$, F (1, 71) = 3.99, p < .01, $\eta 2$ = .15. Separate ANOVAs for the feedback uptake variables were then conducted to the corresponding MANOVA. Results showed that the average score of successful change, F (1, 71) = 1.81, p < .18, $\eta 2$ = .03 was not different between conditions. Yet, results showed that the feedback uptake variables, new error change, F(1, 71) = 6.58, p < .01, $\eta 2$ = .09 and erroneous comment change, F (1, 71) = 4.14, p < .05, $\eta 2$ = .06 were higher for students in the SMS+ condition than for students in the SMS- condition (see Table 5).

The changes above relate to feedback-based changes. We also analyzed the amount of changes that were unrelated to feedback. Apart from feedback-based changes, students engaged in very little revision. Therefore results on revision apart from feedback-based changes are not reported.

	SMS +	(N=34)		SMS-	(N=39)	
Revision types	М	(SD)	Percentage of uptake	М	(SD)	Percentage of uptake
Successful change (SC)	5.06	(1.67)	50.6	5.59	(1.7)	55.9
New error change (NC)	1.03	(1.09)	10.3	1.72	(1.19)	17.2
Incorrect comment change (IC)	.85	(.70)	42.5	1.21	(.77)	60.5

Table 5. Means and standard deviations for feedback uptake

Conclusions

In this study, we explored instructional support that aimed at helping the assessee in the context of peer-feedback. Particularly, we looked at the impact of sense-making support to increase revision skills and feedback uptake during writing. Statistically, sense-making support did not affect revision skills in terms of problem detection and problem correction (hypothesis 1). Results showed increased scores for problem detection in the SMS+ condition and an improvement from pre to posttest. Yet, one can only speculate whether this increase was due to our variation or whether it was by chance because the differences were not significant. It is possible that because of the low sample size, we were unable to detect hypothesized effects. Future studies should aim at larger number of participants per condition. In both conditions (SMS+ and SMS-), we can see that students engaged very little in problem detection can be explained by the peer-feedback that was given. Peer-feedback has the purpose of providing the writer with information on problems in the text thereby helping with problem detection. Peer-feedback might inhibit students to do problem-detection themselves, because there is no need for assessees to detect problems. Future studies should look at how we can support students in problem detection when integrating peer-feedback in instruction.

Sense-making support appeared to affect feedback uptake only to some extent (hypothesis 2). Students in the SMS+ condition showed only on two out of three feedback uptake variables significant better scores. Students receiving sense-making support made less new errors. From the treatment check analysis, we saw that over 90% of the feedback comments that students indicated to use, were actually used in the text to make successful changes. We can conclude that students indeed used the sense-making support table as a way to do a means-ends analysis (Hayes, 2004). Students in the SMS+ condition seemed to relate the errors that were pointed out in the feedback to the actions that need to be taken to improve the text. We can infer that working with sense-making support and using the provided sense-making support table to systematize how to use the feedback might have helped to avoid making erroneous changes in the text. Furthermore, students used less incorrect feedback comments for text changes. These results indicate that sense-making support helped students to reflect on given feedback and to think more deeply which feedback to use for text changes (Schraw, 1998). This picture seems to be confirmed by the treatment-check results. Though we could see that students did use erroneous comments, they did so much less frequently than using the correct feedback. Working with sensemaking support might have helped to become more aware of which comments were correct and which ones were not. Students in the SMS+ condition made as many successful changes as students in the SMS- condition. One reason why sense-making support was not effective regarding successful changes might be the extra work load that students in the SMS+ condition needed to deal with. It is possible that spending time with sensemaking support might have taken away time that students in the SMS- condition could fully spend for making feedback-based changes in the text. Future studies should make sure not to overburden the assessee to leave sufficient time to make changes and to do revision.

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How Did a Grade 5 Community Formulate Progressive, Collective Goals to Sustain Knowledge Building Over a Whole School Year?

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Abstract: This research explores the metacognitive and discursive processes by which a grade 5 community formulated shared deepening goals to direct its inquiry about the human body across a whole school year. This inquiry was facilitated by Idea Thread Mapper (ITM) that supported the community's metacognitive reflection and conversations. Qualitative analysis of classroom activities elaborated the evolution of collective goals of understanding, which were used by students to monitor the community's progress, and regulate further inquiry. Analyses of pre- and post-tests and online discourse showed productive improvement of idea achieved by individuals and the community as a whole.

Keywords: knowledge building, long-term trajectory, socially shared regulation, collective goals, metadiscourse

Introduction

Building on the premise that in the Knowledge Age schools should operate as knowledge-creating organizations to engage students of all levels directly in sustained creative work with ideas (Scardamalia & Bereiter, 1999), recent research efforts strive for innovations to transform classrooms into knowledge-building (or knowledge-creating) communities (Bereiter & Scardamalia, 2014; Bielaczyc et al., 2013). In a knowledge building community, members build on and advance the collective knowledge assets of their community through sustained inquiry and idea improvement: by engaging in idea-centered dialogues involving multiple perspectives, constructive criticism, and distributed expertise; by formulating deeper problems as solutions are developed; and by assuming responsibility at the highest levels instead of relying the leader to direct their actions (Bereiter, 2002; cf. Dunbar, 1997; Sawyer, 2007). The inquiry-based efforts are self-sustained over a long term as a progressive, collective trajectory (Zhang et al., 2012, 2014). This study explores the processes by which a knowledge building community formulates collective deepening goals to develop a progressive shared trajectory of inquiry to sustain knowledge building.

Building a sustained trajectory of inquiry for productive knowledge building requires students to take on collective cognitive responsibility (Scardamalia, 2002). They need to enact socially shared regulation: to construct shared goals, plan collaborative actions, monitor collective progress and engagement, and adapt collaborative processes to optimize members' contribution to achieving their shared outcomes (Järvelä & Hadwin, 2013; Winne, Hadwin, & Perry, 2013). However, collective and socially shared regulation of collaborative learning as an emerging new frontier of research in collaborative learning has mainly focused on short-term collaboration of small groups to solve pre-defined problems or complete pre-specified tasks. In those contexts, students' collective regulation usually focuses on "regulating how to follow the directions, divide up task components, or complete superficial task components" (Rogat & Linnenbrink-Garcia, 2011, p.394). Sustained knowledge building requires all collective members to take much higher levels of responsibility for progressively defining what they need to understand as their understanding is continually advanced over an extended time period (Scardamalia, 2002). As a critical component of such high-level responsibility and regulation, this research explores the evolution of collective shared deepening goals in a knowledge building initiative within a whole school year. In a dynamic system of knowledge building, collective goals are not predefined by the teacher or a student leader, but emerge from ongoing interactive discourse across the social levels of individuals, small groups, and the community. The collective goals of a community are co-constructed on the basis of the emergent goals and interests of individuals or groups and continually reviewed and deepened as progress is made (Zhang et al., 2007, 2009). Therefore, students need to develop reflective awareness of the diverse interests and deepening ideas of their community as reflected in the ongoing discourse, formulate shared deepening goals, plan for joint and complementary contributions, and trace progress (Zhang et al., 2009).

This study supports such collective regulation of long-term knowledge building efforts through metadiscourse: metacognitive conversations about the ongoing conversations focusing on collective goal setting, progress review, and planning (Scardamalia, 2002; Zhang et al., 2009, 2014). In online environments that support knowledge-building discourse and conversations, students' ideas are distributed across individual

postings and comments over time (Suthers et al., 2008). It is hard for students to monitor the shared focuses evolving in the discourse and the progress made, especially in long-term online discourse (Zhang, 2009). To make collective focuses and knowledge trajectories in extended knowledge building discourse visible to students for ongoing reflection in support of progressive deepening goals, our team created a timeline-based collective knowledge mapping tool: Idea Thread Mapper (ITM) (Zhang et al., 2012, 2013). ITM support the metadiscourse and reflection of students: to define focal topics of inquiry, select and visualize important discourse entries addressing each topic, as an idea thread; and map out the whole inquiry as clusters of idea threads that address interrelated problems. The knowledge progress in each idea thread is further reviewed by students through co-authoring a "Journey of Thinking" synthesis focusing on focal problems, "big ideas" advanced along the inquiry process, and deeper actions needed for further work. This research examines how a grade 5 science community developed collective shared progressive goals to foster sustained knowledge building supported by ITM and related classroom artifacts.

Methods

Classroom contexts

The study was conducted in a grade 5 classroom (with 22 students in the fall and 21 students in the spring) in upstate New York. The students investigated human body systems over a whole school year, with two science lessons each week. Prior to this study, the teacher, who had 10 years of teaching experience, participated in a three-day workshop to learn about knowledge building principles and activity designs (Scardamalia, 2002; Zhang et al., 2011). Following the knowledge building principles, students engaged in all kinds of knowledge activities to expand their community's knowledge, including individual and small group reading and online searching, whole class meetings to share and reflect on work in progress, student-directed experiments and creation of knowledge artifacts, as well as student-designed presentations about individual and small group knowledge advancement. Initial wonderments, improved ideas, deepened questions, and refined theories from these activities were shared in Knowledge Forum (Scardamalia & Bereiter, 2006) for continual knowledge building discourse. To make collective knowledge progress in online discourse visible to students, we used ITM in the middle (early January) and at the end of the school year (late May and early June). During all these knowledge building activities, the teacher, who positioned himself as a facilitator and co-learner, encouraged students to take on collective responsibility (Zhang et al., 2009) to identify collective knowledge goals, plan collaborative activities, share and reflect on ongoing progress within the community.

Data sources and analyses

To examine the effectiveness of knowledge building, we conducted a pre-test in mid-September and a post-test in early March. The test had nine open-ended questions that required students to explain how different human body systems work together. Due to student changes over this school year and schedule conflict, only 13 students took both the pre-test and post-test. Student answers were rated in terms of scientific sophistication, which examined the extent to which students' ideas align with a scientific framework on a five-point scale: 0 - no answer, 1 - pre-scientific, 2 - hybrid, 3 - basically scientific, and <math>4 - scientific based on our previous studies (Zhang et al. 2007). Using this coding scheme, two raters independently coded all the answers, resulting in an inter-rate agreement of 99.15% (*Cohen's Kappa*= 0.98).

To trace the evolution of collective goals and related inquiry, we conducted qualitative analysis with rich classroom data. Specifically, we analyzed observation notes that recorded classroom activities across the whole school year. A close examination of those notes helped to identify the most critical moments when collective goals were formed, adapted, and represented using related classroom artifacts (e.g. a collective wondering list). We then selectively zoomed into relevant videos of the classroom moments to understand the process of goal evolution. The videos were transcribed and analyzed using a narrative approach to video analysis (Derry et al., 2010). Complementing the video data of the whole class processes, we also analyzed three students' notebooks using content analysis (Chi, 1997) focusing on the goals of inquiry.

To examine how individuals, small groups, and the whole community carried out inquiry and discourse to address the collective goals, we conducted content analysis of student's online discourse, idea threads and Journey of Thinking recorded in ITM, and their final presentation posters at the end the academic year. Each Knowledge Forum note was coded using the coding scheme presented in Table 1 focusing on the emergent collective goals in this community. Two raters independently code 20% of the notes (667 in total) to assess inter-rater reliability, which was found to be 98.5% in inter-rater agreement (*Cohen's Kappa* = 0.95).

Focal goal	Description	Example
1. Why do we have muscular and skeleton system? Students ask questions or share information, about bones and muscles.		"How many bones, muscles, and joints are there in the human body?"
2. How does the brain function?	Students make notes about the architecture of the brain, roles of the different parts in the brain and related nerves to support thinking and sense.	"The brain sends the messages to your brain stem, the brain stem then sends the messages straight to your spinal cord. Then it sends it to the appropriate nerve."
3. How does the human body develop?	Students ask questions, or share information about the functions of different body parts.	"We have nose hair so the dust won't go all the way into our nose and some dust do have germs."
4. How does the immune system work?	Students ask questions or share information about allergies, diseases, germs, virus, drugs and health issues.	"Maybe HIV won't kill you it will just shut down your immune system so other virus can do the job."
5. Why do we have a digestion system?	Students make notes about food, nutrients, energy transfer, as well as the organs that function as part of the digestion system.	"Did you know that your teeth is part of your digestive system? Because that helps you chew food and send it down to your stomach. Teeth is your first part of your digestive system."
6. Why does blood circulate through the human body?	Students share information or ask questions about heart, blood vessels, veins, and how nutrients, oxygen, carbon dioxide are transported.	"What does the blood carry through the human body? I know that blood carries oxygen, but does it carry anything else? Does blood carry carbon dioxide too?"
7. How do vocal cords work?	Students make notes about how we talk, the structure of the vocal cords, and how do they help to make sound.	"Vocal cords vibrate to make sounds but what makes the vocal cords vibrate?"
8. How does the respiration system work?	Students make notes about the organs that help to breathe and explain the process that oxygen is delivered into the body and carbon dioxide is taken out.	"Why do we sneeze? What happens inside the body when you sneeze?"
9. Why do we have cells?	Student share information or ask questions about the structure, types and functions of cells.	"Without glia cells our neurons would not work properly. With trillion of support cells it helps a lot with the neurons."

Table 1: Content analysis of students' online discourse based on collective goals of inquiry

Findings

Content analysis of students' pre-test and post-test

Individual knowledge advancement was assessed based on the pre- and post-test that focused on deep explanations. A paired samples *t*-test revealed a significant difference between the pre-test (M=1.43, SD=0.63) and post-test (M=2.99, SD=0.78), t (13) =-7.61, p<.001. Specifically, students' ideas were mostly "2 – hybrid" at the beginning and mostly "3 – basically scientific" in the post-test.

Qualitative analysis of classroom observation notes, classroom videos, and students' notebooks

This inquiry began with a kick-off activity in late September. Students watched a short movie that triggered deep interests in the amazing functions of the human body. Understanding how the human body works was identified as the overarching topic of this year's inquiry. The whole class began to negotiate collective goals after the kick-off. The negotiation originated from initial questions that students were really curious about. The teacher collected all those questions and read them one by one to students. Students realized that some of them were posing the same or similar issues. Therefore, the teacher suggested the students to work in groups to integrate these individual questions and encouraged students to rephrase them in a more scientific way. By the end of the first week (September 24), they came up with an initial list of four collective questions, as the community's shared goals: Why do we have bones? How does our brain function? How does the human body develop? How does immune system work? Then the teacher used the metaphor of a tree trunk and branches to visualize the collective questions, and encouraged student to add more big branches to the community tree as their inquiry proceeded. One week later, students had a metacognitive meeting to share and reflect on collective knowledge progress. They sat in a circle, read KF notes projected on a screen together, and found that some of the notes "didn't fit existing collective questions." So students suggested that they might need new collective

questions. Therefore, they generated the fifth collective question based on notes about food and water—Why do we have a digestion system? (Added on October 1)—and the sixth collective question related to heart and blood: Why does blood circulate through the human body? (Added on October 3). The six knowledge goals were recorded on a chart paper, which was posted on the classroom wall as a collective guide (see Figure 1). Each student then chose one big question as his/her focal area based on interest and added the name on a sticker note next to the question, leading to the formation of temporary/ flexible research groups. The teacher encouraged students to add more "branches" onto the collective question list if none of the questions reflected their focal interest. Two students who had done initial research about vocal cords talked to the teacher. The teacher suggested that they start a new area about vocal cords, with two additional students who shared the same interest. The seventh question about how vocal cords work was added to the collective goal list on October 10. During the following two months, students did focused research on these themes while having the flexibility to switch between these areas as their interest evolved. They made posters and models to show new ideas about their focal question, and shared findings/further questions in face-to-face whole class meetings and on KF. Later, through a whole class reflection on knowledge advancement, students identified new goals in reflection of expanded aspects of their inquiry. On December 12, two new questions were identified: Why do we have respiratory system, and how do human body cells work? Interestingly, as part of the reflection on collective knowledge progress, a student proposed a question about muscles as a new big question. His peers who investigated bones suggested that this question about muscles could be integrated in the existing question about bones as the two are so closely related. On January 9, the first big question was renamed as "why do we have muscular and skeleton system?" Altogether nine collective questions, representing the shared goals of inquiry, were progressively formulated (see Figure 1) and continually investigated in the rest of the inquiry.

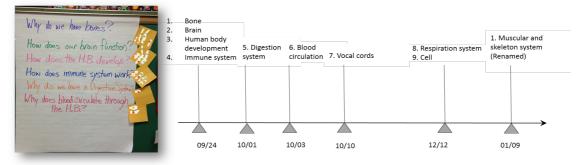


Figure 1. Evolution of shared goals of inquiry.

These goals originated from students' initial curiosities were refined and reframed through metacognitive conversations about diverse ideas and questions presented in the ongoing face-to-face and online discourse. The excerpt below shows an example of such metacognitive conversations to review existing questions and formulate collective questions. The teacher, as a co-learner, played a critical role in helping clarify initial wonderings to connect with deep domain knowledge in the area of human body research.

Teacher:	So far, we have "why do we have bones", "how does the brain function?" and "how do human bodies develop?" What's that?
Student 1:	Why do we have nose?
Student 2:	That would be a question under the human body development
Teacher:	Is that aNow, I'm asking you. Okay, please, please, whyis that a big branch? Or is that a smaller branch that could be added to something else? Now I have allergies. Is there any ideas that I can have the serious focus with you? I have a larger mouth, stuffing my nose, every single day. So nose, nose, nose goes where
Student 3:	Why do we have mucus?
Teacher:	MucusWhy do I have mucus? Mucus problemsThey are always there, but when do you notice it? When you have mucus problemswhen you were sick. So can we make a bigger idea about something like?
Student 4:	Health?
Student 5:	Why do we have health issues?
Teacher:	So there is a little question. Have you guys ever heard of immune system?

Students:	(together) OhYes!!!
Teacher:	Is that what we were talking about? Does that sound like something that a
	big branch looks like?
Students:	(together) (Nod)
Teacher:	So let's try, write down something about immune systemHow could you guys phrase something about the immune system?
Student 6:	How does immune system help us?
Teacher:	WowAll right (write it on the poster). How doesimmune systemWhat's it?
Student 4:	Work?
Teacher:	(write on the poster) All right, that's pretty awesome. You guys generated the branches (pointing at the questions on the poster) all these things.

The teacher, as well as the community as a whole, was open to including new questions from students into the list of collective goals. The emergence of the vocal cords as an inquiry area is a sound example. On October 8, student A read the book Kids InfoBits written by Beth Allen. She was really interested in the part about vocal cords and took some notes in her notebook. Even though she had signed up for the immune system inquiry, she talked to the teacher about her new interest in how vocal cords work. Meanwhile, student B who, was still hesitant about which group he should join in, read the magazine Science Spin (Primary). He took some notes about how sound is produced through air vibration. Since he was not sure about his focus question, the teacher suggested that he started with what he was working on. Student C, who had signed up for the immune system, sitting next to student B, indicated the same interest in vocal cords, with some notes taken about pitches of vocal cords. Student D, who had not decided a focus area, showed interest in this new question. Therefore, these four members formed into a temporary group to study vocal cords.

Content analysis of students' contributions in online discourse

To examine how collective goals guided student participation in the online discourse, we coded students' KF notes based on the collective goals. Table 2 shows the number of notes created and the number of contributors involved before and after the formation of each goal, with the date when each goal was formally added as the cutting point. For example, the question about vocal cords was identified as the seventh collective goal on October 10. Therefore, October 10 was used as the cutting point for the calculation.

Collective observed goals	Before th	ne formation	After the formation	
Collective shared goals	Notes	Authors	Notes	Authors
1. Why do we have bones (muscular and skeleton system)?	0	0	21	8
2. How does the brain function?	0	0	131	24
3. How does the human body develop?	0	0	125	24
4. How does immune system work?	0	0	194	23
5. Why do we have a digestion system?	3	3	25	10
6. Why does blood circulate through the human body?	12	11	65	19
7. How do vocal cords work?	1	1	25	11
8. How does respiration system work?	2	2	3	3
9. Why do we have cells?	17	9	60	18

Table 2: The number of notes and authors before and after the formation of each collective goal

The first four goals represent a pattern of goal formulation driving subsequent discourse. The first four goals were identified in the beginning of the inquiry on September 24 based on student questions raised in face-to-face talks and written on Post-It notes. Therefore, no KF note was written before the formation of these goals. As the Table 2 indicates, these focal areas attracted intensive online discourse contributions of students. In the early phase, the contributions in each area were mostly from members of the corresponding specialized group who signed up for the research. Interestingly, as the inquiry deepened and cross-theme connections became evident, students contributed notes to discuss interrelated issues and further posted information beyond their own focal areas. This was most evident in goal 2-4 that engaged contributions from almost every student. The collective goals, which were treated as open-ended and evolving, guided the formation of specialized inquiry groups while allowing students to interact flexibly within the whole community to address interrelated issues.

The online discourse about how vocal cords work provides an example of collective goal emergence based on individual contributions specialized in a topic, opening up a line of inquiry. Before the goal about vocal cords was formally identified, there was only one member from the human body development group asking "how do we talk". One week later, after the formation of this goal, the four members began to share findings about location of vocal cords, and how the vocal cords works through vibration. They also built on the initial question "how do we talk". After noticing the progress of work about this goal, the contributor of the first question came back to share his experience that could be well explained with newly shared information. These contributions caught the attention of a student from the brain function group. He joined in the conversation by requesting more details about "larynx". A girl from the blood circulation group noticed these notes and joined in this talk, asking about the relationship between the thickness of pitches and the changes of voice at different ages. Meanwhile, a member in the group asked, "Vocal cords vibrate to make sounds but what makes the vocal cords vibrate?" Another student from the human body development group contributed to the vibration issue with an explanation of air moves. With a collective focus on the same goal, progressive ideas and questions emerged with ongoing interactive discourse online, which further pushed the conversation to a deeper level.

Another interesting pattern was seen in the origin of cells as a collective goal. It emerged from the ongoing discourse across a range of topics that converged focusing on issues about cells. Before the formation of this goal, students investigating the immune system, bones, blood circulation, brain functions, and the human body development started to talk about cells in their own contexts: members from immune system group focused on white blood cells; members from the bone group were interested in how bone marrow made red blood cells; members from blood circulation group discussed the function of red blood cells; members from the brain function group devoted to how support cells protected neurons; while members from human body development group were sharing information about skin and tissue cells. As more students joined in the conversation, a collective goal was brought up on December 12. As Table 2 indicates, nine more students joined in this conversation after the formation of this goal. New members began to contribute to it by making connections to their focal area. For example, a girl from the bones group made the following note on KF: "My theory is that bones are also made of cells. Some bone cells are star shaped. How many different types of bone cells are there and what do they look like? I can't find anything more in depth". A new member who joined in in the later part built on previous work with this note: "The only thing that I know was the white blood cells but now I combine what student A say and student B say so now I know the red blood cells". Those who had been in this group for a while moved onto discussion about cell itself, including different types of cells, the functions of them, and different parts in a cell. As the conversation moved to a deeper level, a student who had been doing research on cells questioned herself and wanted to know more about the jobs of different parts of a cell: "I have been researching about the parts of a cell. I would like to find out why cells need different parts, and what each part does. I will write about the important facts soon!" In the later part of their conversation, even deeper issues about DNA, RNA, and cancers were brought up: "I can't explain what is a DNA and RNA'; "Cancer is grown out of control cell. Cancers only happen when something is wrong with your DNA your body will fix it."

Video analysis of ITM-aided reflection

To reflect on knowledge progress in achieving collective goals, students conducted the first ITM reflection in early January, and another ITM reflection session in late May. They engaged in metadiscourse to organize idea threads based on the collective goals and co-authored "Journey of Thinking" synthesis for each thread.

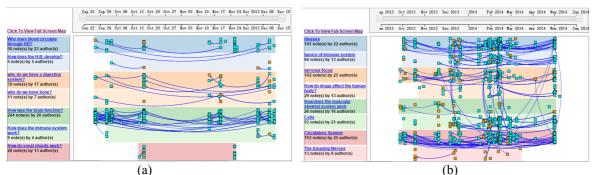


Figure 2. Idea threads created in the first ITM session (a) and the second ITM session (b).

In the first ITM reflection, students worked in small groups to review contributions on KF that addressed each collective goal. In each group, students used ITM to search for notes addressing their focal topic with co-identified keywords, and screened and added relevant notes to their thread. Seven idea threads were

created: 1) why do we have bone? 2) how does the brain function? 3) how does the human body develop? 4) how does the immune system work? 5) why do we have a digestion system? 6) why does the blood circulate? 7) how do vocal cords work? ITM displayed selected notes on a timeline as an idea thread (see Figure 2a) and further retrieved authors involved in this work, with options to show build-on connections over time. For example, the thread created for circulatory system included 50 notes contributed by 23 authors. In the early phase of inquiry, students wrote several notes about this question. However, no contributions were made from mid-October to mid-November. While in December, they came back to deepen ideas in this thread.

In the second ITM session near the end of the school year, students reviewed idea progress focusing on areas that had active contributions since the first ITM. Five emergent groups formed to set up and review idea threads using ITM focusing on the muscular and skeletal system, nervous system, immune system, circulatory system, and cells. When working on the keywords to search notes on KF, students focusing on the nervous system and immune system found they had rich contents addressed, so they decided to break down into several sub-groups focusing on more specific issues. Eventually, eight threads were created (see Figure 2b): 1) how does the muscular and skeletal system work; 2) nervous focus (basics of nervous system); 3) the amazing nerves (the functions of nerves in messaging); 4) basics of immune system; 5) diseases; 6) how do drugs affect the human body? 7) circulatory system; and 8) cells. Comparing the intensity of notes created in each thread in the two ITM sessions, it is obvious that more new contributions were made after the first ITM session from early February to March. With reflective monitoring of progress in each collective goal through idea thread, students made purposeful contributions and collaborations in subsequent work.

The knowledge progress in each thread in the second session was further made transparent through the Journey of Thinking synthesis. Analysis of the Journey of Thinking suggested that the students effectively identified problems as the collective goals, highlighted conceptual advances achieved in online discourse, and identified deeper questions to be understood. Table 3 shows the joint efforts of three students from "the amazing nerves" group synthesizing the community's progress on nerves across the whole year.

Table 3: Journey	of Thinking s	vnthesis for nerves

Our problems	Big ideas learned	Need to do more
At first, we had a huge	The glial cells protect your neurons. If your brain have too	We obviously did not have time so
question about the	much memories it will delete a little bit of the memories.	far to learn everything there is
brain. The question	So there are enough for new memories. You right brain	about the brain. We need to learn
was: How does our	controls your left side of the body and your left brain	more about how fast the brain can
brain function? At this	controls the right side of your body. We got these new	send messages throughout the
point, which was	ideas as we answered the first question. Then we got	human body and the nerves. We
basically October, we	VERY deep and scientific. We learned new facts: without	need to know more about
had basic ideas about	cells there won't be a nervous system. If there is no blood	neurotransmitters. We gave to
the 3 parts of the brain,	circulation. The nervous system won't work. Brain is the	learn about how those little fat
and the right and left	important part of your body. However, the brain won't	cells that do something we don't
side of the brain.	function without the other parts.	know!

Discussion

In this study, the course of the whole year inquiry unfolded in an emergent and improvised manner driven by progressively expanded/deepened discourse. Students engaged in metacognitive conversations to review the ideas and questions emerged in inquiry and online discourse to formulate collective deepening goals, reflect on progress made, and plan for deeper inquiry. The analysis of the pre- and post-tests showed the productivity of the community in building deep understanding of how the human body systems work. (The productivity is also evident in our content-based coding of online discourse based on epistemic contributions, which is not reported in this paper.) The qualitative analysis provided a detailed account of the evolution of the collective deepening goals, which were repeatedly used and referred to in the subsequent inquiry to guide student participation, discourse, and progress review and sharing. The collective goals emerged and evolved through several reflective cycles: formulating an initial list of four big "juicy" questions based on diverse individual interests and questions, expanding the list to include questions about digestive systems and vocal cords based on individual and collaborative proposes, reframing existing goals in reflection of new emergent issues, and developing new conceptual goals (e.g. cells) at the intersection of different lines of work focusing on deep concepts identified. The collective goals were co-constructed and continually adapted by the community through metacognitive conversations in reflection of members' diverse input and ongoing progress. These collective goals were represented and highlighted using classroom artifacts (e.g. collective question list) to guide student attention and participation. Students referred to and revisited these goals in classroom discussions, formed into flexible topicbased groups to conduct specialized research, participated in online discourse to share and discuss findings and deepening issues; and used collective questions as focuses to set up idea threads in ITM and synthesize progress made. Based on the ITM Journey of Thinking syntheses, students further created poster presentations to share knowledge within their own and with peer classrooms. These findings shed light on the possibility and processes for young students to enact high-level regulation of long-term knowledge building initiatives. Collective metadiscourse supported by ITM provides a design to support such high-level regulation for students to formulate progressive goals and reflect on progress (see also, Zhang et al., 2013, 2014). Deeper analysis of classroom videos is underway to further understand the patterns of metadiscourse and the teacher's roles.

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Activity Design Models to Support the Development of High Quality Collaborative Processes in Online Settings

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Abstract: In this paper we assess the utility of an activity design model and different reflective activities for improving the quality of collaborative processes. Thirty-seven online students, belonging to one of 13 teams, formed the participants of the study. Teams completed five discussion sessions as part of required course activity, using one of two reflective conditions. Each team also received feedback on their performance. We assessed the quality of processes between groups using content analysis techniques. Team process measures at the first time point were used to identify groups' initial strengths and weaknesses. To assess the utility of the model and reflective assessment designs, we used a 2x5 mixed factorial design, with Condition (two levels) as a between subjects factor and Time (5 levels) as a within subjects factor. We found that students were weakest at presenting and discussing claims and both Condition and Time are significant predictors of collaborative process quality.

Keywords: sociometacognition, regulation of collaborative processes, assessment, discussion quality, online learning, online collaboration

Introduction

Collaborative learning can provide many benefits for learners, but the outcomes of collaborative activities are dependent upon the quality of collaborative interactions that occur during activity (Barron, 2003; Kozlowski & Ilgen, 2006; Stahl, 2006). This is problematic since many students lack the cognitive skills necessary to engage in high quality collaborative interactions (Borge & Carroll, 2010; Carroll, Jiang, & Borge, 2014; Fischer et al., 2013; Hogan, 1999a; Stegmann, Mu, Gehlen-Baum, & Fischer, 2011). When left to their own devices, students commonly develop dysfunctional group processes that negatively affect collective cognitive processes, learning, and performance outcomes (Barron, 2003; Borge & Carroll, 2014; Hogan 1999b; Webb & Palincsar, 1999). Thus, there is a need to develop activity design models to help students' understand what high quality collaborative processes entail and apply this knowledge to regulate existing collaborative activity.

We are currently working on the design of a CSCL environment that supports students as they learn to collectively regulate collaborative discussions. As we design the system, we are iteratively collecting data to inform the design of activities and features in the system. In this paper, we evaluate a model for the design of activities and reflective features to improve the quality of collaborative processes that occur as students discuss and think about course concepts as part of regular course activity. Our approach takes advantage of the affordances of online technology to turn the process of learning into the product to be assessed. We present findings from an implementation that took place as part of an online introductory course on information sciences and technologies, identify specific needs of the population, and examine the extent to which our activity design model and different types of reflective activities were associated with improvement of collaborative processes over time.

Related literature

Researchers have developed different types of designs to structure and guide collaborative activity, but deciding on the type and level of support can be a challenge. For example, collaborative scripts are pedagogical or dialogical models designed to optimize collaborative processes by structuring, prompting, or constraining different behaviors (Dillenbourg & Hong, 2008). However, there are trade-offs associated with scripting. On the one hand, high levels of scripting may help students produce better quality discussions and products in the short term. On the other hand, too much scripting may prevent students from recognizing gaps in learning and putting forth the cognitive efforts to fill those gaps (Bjork, 1994; Kapur & Rummel, 2009). The challenge when providing cognitive scaffolds is to ensure that they are temporary support structures and not permanent fixtures. Providing too much guidance during collaborative discourse may not be the best approach to helping students internalize sophisticated reasoning processes because an external source is telling students what to do rather than helping students learn how to regulate learning activity for themselves. Researchers in the field of self-regulated learning have argued that effective regulation is a cyclical process of planning, doing, and reflecting (Zimmerman, 2002). To effectively self-regulate, students need to understand and think about the task in order to plan their approach, monitor themselves as they perform the task, and then reflect on their performance based on their understanding of the task in order to revise their approach (Boekarts, 1996; White & Frederiksen, 1998). Unfortunately, most students do not display optimal self-regulatory behaviors (Winne & Hadwin, 1998). Similarly, students also do not display optimal collective regulatory behaviors (Jarvela & Hadwin, 2013). However, laboratory studies in social psychology have shown that with training teams can improve task performance through collective regulation (DeShon et al., 2004). Whether similar types of training in classroom settings could improve students' ability to self-assess and regulate collaborative processes remains to be seen.

Given the complex and evolving nature of collaborative activity, it is likely that development of sociometacognition, the executive control of collective cognitive processes, may be a necessary prerequisite to ensure that students can consistently display collaborative processes known to promote learning and problem-solving success (Barron, 2003; Jarvela & Hadwin, 2013). The ability to regulate individual cognitive activity is positively associated with higher quality individual cognitive processes and learning outcomes (Schraw, 1998; Schoenfeld, 1998; White & Frederiksen, 1998). Therefore, it is likely that the ability to regulate collective processes will facilitate higher quality collaborative activity over time.

Based on problems associated with collaborative activities and the potential benefits associated with the development of sociometacognition, we propose an activity design model for improving the quality of collaborative discussions in classroom settings that involves iterative cycles of sociometacognitive development: students prepare for collaborative discussions, engage in collaborative discussions, assess the quality of their collaborative discussions using reflective assessments (Shimoda, White, Borge, & Frederiksen, 2013), receive feedback on group process, and then repeat the cycle. The main aim of the collaborative discussions is not to engage in formal scientific inquiry, but rather to engage in questioning and deeper analysis of scientific course content. During collaborative discussions, students receive general instructions to help structure the discussion task and ordering of discussion topics, but they receive no support during the discussion session to help them select, organize, share, or interpret information, or modify their interactions. After engaging in an online discussion, students evaluate their discussion as an object of thought. By making the discussion the product to be submitted and evaluated, students have more time to think about their collective processes than they would if they had to submit another deliverable. Finally, to account for problems associated with inaccuracies of selfassessment (Burser, Larrik, Clayman, 2006; Kruger & Dunning, 1999), students calibrate their individual reflective assessments through collective discussion combined with expert feedback. Students repeat these activities for every new discussion with the aim of improving the quality of their collaborative discussions.

Currently we require students to focus on developing two capacities, information synthesis and knowledge negotiation. These two capacities are crucial to collective cognitive processes in computer supported collaborative learning (CSCL) and collaborative work (CSCW) environments (Borge & Carroll, 2010; Stahl et al., 2006; Carroll et al., 2014). Thus, they serve as the starting point in our design model to support the development of sociometacognition.

Study aims and research questions

In this study we examine the quality of collaborative processes of students enrolled in an online course and the extent to which the use of our activity design model helps students improve two core collaborative capacities: information synthesis and knowledge negotiation. Our research questions are as follows:

- (RQ1) What are the most common problems students face that interfere with high quality collaborative reasoning?
- (RQ2) To what extent does our activity design model and differing reflective-assessment activities affect teams' improvement of collaborative reasoning over time?

Methods

Study context

The study took place in a 16-week university level introductory online course on information sciences and technology. The main aim of the course was to introduce students to concepts and research areas central to information sciences, i.e., security and risk analysis, human computer interaction, emerging technologies, effects of technology on society, and informatics. The course was organized in a learning management system (LMS), with weekly lessons, student resources, course communication, and course materials all housed in the LMS. The instructor of the course was expected to organize and maintain the course, revise instructional materials as

needed, grade student work, answer student questions, and help students to think more deeply about course content. As part of the course, students had to learn to work as part of effective teams and had to complete a team project. For this reason, developing better collaborative reasoning practices is a required part of the course and the discussion activities count towards 25% of their total grade.

Research design

We used quantitative and qualitative analysis techniques to examine students' collaborative processes and learning over time, with teams as the unit of analysis. We used a 2×5 mixed factorial design, with Condition (two levels) as a between subjects factor and Time (5 levels) as a within subjects factor. The quality of processes between groups was assessed using content analysis techniques. Team process measures at the first time point were used to identify groups' initial strengths and weaknesses.

Participants

Thirty-seven online students formed the participants of the study, each belonging to one of 13 groups. Eleven students (30.5%) were female and 25 students (69.4%) were male. The female to male ratio was fairly representative of the enrollment of information sciences and technology courses at this college. The groups were formed with consideration to availability for online group meetings, gender, expertise in information sciences and technology, and employment status. Groups were assigned to condition A, future thinking, or condition B, evidence, such that the groups in each condition were comparable. There were five females in condition A, six in condition B. Seventy-one percent of participants in condition A were in the 25 - 44 age range; 75% were in the 25 - 44 age range in condition B. With regard to group composition, there were five teams of three and one team of two in condition A; six teams of three and one team of two in condition A, 66.7% of the teams were majority male compared to 71.4% in condition B. Neither group had all female teams. Of those that reported work hours, 91.6 % reported working full time in condition A; 90% reported working fulltime in condition B.

Instructional activity design and implementation

As part of the course, students were required to read a chapter from the required text or supplementary materials each week. The pervasive practice for holding students accountable for readings in other sections of this course is requiring students to take multiple choice quizzes, but we wanted to provide opportunities for collaborative discourse. For this reason, students were assigned to teams in weeks three through five and in weeks six, eight, ten, twelve, and fifteen, we replaced required multiple choice quizzes with graded, synchronous discussions about reading content. On weeks when students had to complete the collaborative discussion, students had to set a meeting time with their teammates, and individually complete a pre-discussion activity and review the discussion session materials before the meeting. In session one, teams received full credit for the discussion regardless of the discussion quality. After the first session, students were given initial assessments and told that the subsequent discussions would be graded based on discussion quality.

The pre-discussion activity

We created a pre-discussion activity to help students organize their thinking around the required readings. The activity consisted five questions: (1) what were the main learning goals of the chapter, (2) what was the most difficult concepts or parts of the reading, (3) what did you find most interesting, (4) what four questions could you ask yourself, the authors, or others regarding this chapter, and (5) were you able to fully meet the learning goals for this chapter. Students had to respond to these questions and submit their responses before their discussion session.

The discussion materials

The discussion materials, housed in the LMS throughout the course duration, included a group process rubric detailing how we would assess discussion quality. We also provided students with guides containing goals and strategies associated with different collaborative capacities including information synthesis and knowledge negotiation.

The discussion sessions

The discussion sessions were held in a professional collaborative workspace with chat and document sharing capabilities. Use of video during discussion sessions was not allowed for two reasons: (1) many of our students lack access to high-speed Internet and (2) use of video would likely degrade chat quality. Each team had an assigned space that they could log in to and maintain for the duration of the course. Students were required to

export their chat files after completing the discussion sessions. The exported files had to be submitted to a drop box folder in the LMS.

There were three parts to the discussion session, each with a different allotted amount of time for completion. Students were advised to spend no more than 1.5 hours to complete the entire three-part session. In part one, the team had 60-minutes to discuss questions and issues raised by the pre-discussion activity. Each team was also required to create and submit an outline of their discussion. In part two, the team had 15 minutes to individually assess the quality of their discussion session using the provided group process rubric, without communicating with other members. We informed students that an expert rater would assess the quality of their discussions and that we would determine the accuracy of their scores based on the difference between their scores and the expert score. The instructions stated, "it is more important to be accurate than it is to say your team did well. It will not help your team at all to give yourselves high scores. It is better to be critical, as this will help your team improve." Students were required to submit their individual assessments to a drop box in the LMS before moving on to part three. In part three, the team had 15 minutes to discuss how each team member assessed the team, identify their strengths and weaknesses, and select strategies from the materials provided that they could use to improve their collaborative discussion processes.

Assessment of collaborative discourse quality

We designed an assessment for determining the quality of online discussions by adapting a video-based collaborative interaction analysis rubric developed by Borge & Carroll (2010). After each discussion session, individual students evaluated the quality information synthesis and knowledge negotiation by completing this assessment. A research assistant with two years of communication analysis training used the same assessment to evaluate each team's discussion using their submitted chat files. There are three categories of behavior within each of the two core capacities, with each category assessed on a five-item, ordinal scale. Twenty percent of the total data was double coded by the research assistant and another trained graduate student to determine interrater reliability of the instrument: r = 0.86; p < 0.001, Kappa = 0.64; p < 0.001. Once each item of a core capacity is rated, they are averaged to produce a single Collaborative Discussion Quality score, which is a continuous value between 0 and 5 that we use to track improvement over time in collaborative discussion processes in the analysis below.

The first core capacity, information synthesis, consists of three categories of behavior. (1) Verbal participation examines the amount of turns of speech contributed by each member relative to the team's total turns of speech. Each chat message on the chat file is taken as a turn of speech. A score of one means that one member contributed most turns of speech and at least one member barely contributed. A score of five means all members contributed equally to the conversation. (2) Developing joint understanding evaluates the extent to which teams make an effort to ensure that members fully understand the ideas presented by taking time to reword, rephrase, or ask for further clarification of shared information. A score of one means that the team showed no instances of rewording, summarizing, or confirming another member's idea or decision, or a possible team action. A score of five means two criteria were met: (i) at least two instances exist where a member reworded another member's idea to make sure he/she understood it or asked another member to explain an idea by elaborating further, and (ii) at least one example exists of synthesizing major decisions or multiple ideas of members. (3) Joint idea building focuses on the extent to which team members elaborate on another member's contribution in order to ensure that information introduced by any member is not ignored or accepted, without discussion. A score of one means there were no instances where members extended or clarified another member's shared information; members ignored others, posed different suggestions unrelated to the original idea, or simply accepted the idea and moved on. A score of five means there were two or more instances where one or more members added to another's idea by extending or clarifying over more than five turns and there were no instances where members ignored others or posed different suggestions unrelated to the original idea.

The next core capacity, known as knowledge negotiation, also consists of three categories of behavior. (1) *Contributing alternative ideas* evaluates the extent to which teams present and discuss alternative perspectives, claims, or suggestions. A score of one means there were no instances where a claim or suggestion was followed by another member prompting for a counter claim, pointing out a problem, or sharing an alternative viewpoint. A score of five means that there were at least two examples where a claim was followed by another member prompting for a counter claim, pointing out a problem with a claim, or sharing an alternative viewpoint, and a discussion lasting over five turns ensues as a result. (2) *Quality of claims* focuses on evaluating the extent to which teams provide logical, fact-based evidence and rationale. A score of one means that when members made claims they did not include any rationale, evidence, or weighing of options. A score of five means there were supported by logical, evidence-based rationale or weighing of different options. (3) *Norms of evaluation* focuses on evaluating the extent to which teams adhere to

social norms that promote the development of psychological safety, "a shared belief held by members of a team that the team is safe for interpersonal risk taking" (Edmondson, 1999). A score of one means that members repeatedly used extremely inappropriate or offensive language (i.e., blatant profanity, vulgarity, racist or sexist language, etc.), or examples exist where a member attacks another member's intelligence or character (e.g. "you don't know what you're talking about"), or made disrespectful comments about a member's ideas (e.g. "that is stupid"). A score of five means that responses were professional and respectful with at least one instance where a member acknowledged that an opinion or claim of another member is reasonable or justifiable before pointing out its flaws or presenting a counter argument. Also, no examples exist where a member attacked another's intelligence or character, made disrespectful comments about an idea, or used inappropriate or offensive language (i.e., racist, sexist, or sexual in content).

Findings

(RQ1) What are the most common types of problems that interfere with high quality collaborative discourse practices?

In the first session, students completed the discussion activity based on their initial collaborative predispositions. We used expert ratings from this first session to identify the most common problems faced by our online population of students.

With regard to information synthesis, we found our online students were good at extending the ideas of teammates and developing shared understanding with teammates; these were the two highest average scoring areas (see table 1 for population means and modes by process). Though our population scored high on information synthesis overall, they experienced problems associated with verbal participation. Most of our teams, eight out of the thirteen teams, had one person dominate the majority of the team's discussion.

We found that our population of online students had more problems with collective knowledge negotiation than they did with collective information synthesis. The only item in knowledge negotiation that our population was able to perform at an average range was developing norms of constructive evaluation. Eleven out of the thirteen teams scored at an average level on this item, meaning that the teams primarily focused on evaluating ideas and not the people who suggested them. Teams were also not rude or hostile when evaluating claims. However, only two teams took time to acknowledge that an opinion or claim was reasonable or justifiable before pointing out flaws or presenting counter arguments.

When we examined the extent to which team members provided alternative ideas or counterclaims, we found that over half of our teams displayed processes at or below average. Three teams had slightly dysfunctional processes with regard to providing alternative ideas: people were prompting for counter claims or alternative viewpoints, but counter claims and alternative viewpoints were rejected or ignored without discussion. Four teams scored in the average range, meaning there was at least one example of someone prompting for or providing an alternative claim or opposing viewpoint and team members did not reject or ignore counter arguments or alternative viewpoints, but alternative claims or opposing viewpoint were immediately followed by agreement rather than discussion.

	Collecti	ve Information Sy	ynthesis	Collective	e Knowledge Ne	gotiation
	Verbal Participation	Joint Understanding	Idea Building	Alternative ideas	Quality of Claims	Norms of Evaluation
Mean	2.62	4.54	4.54	3.38	3.31	3.31
Mode	2.00	5.00	5.00	2.00	2.00	3.00
Std. Dev.	1.30	0.51	0.80	1.24	1.22	0.78

Table 1: The mean, mode, and standard deviation of each item of the assessment for our population. Teams were rated on a scale from one to five, where a score of two indicated some level of dysfunctional behavior

Quality of claims was also a problem for our teams. The most common score on the assessment was a score of two, indicating below average quality of claims. Teams with slightly dysfunctional quality of claims did not support any of the claims made during their session with logic-based rationale. These teams provided only shallow rationale; they did not weigh ideas or provide a chain of logical reasons to argue for or against a claim:

Turn	Speaker	Contribution
1	Tom:	Without databases all the logistics of our planet today would be a nightmare.
2	Pete:	Yes it makes everything way more efficient
3	Rob:	Yeah I can't imagine a world without databases
4	Tom:	I think the chapter could have touched on more SQL language bits
		it was mentioned for about 5 seconds and then gone

The team makes four claims in each turn of this short episode. Turns 1-3 include a claim with no rationale or evidence. In Turn 4, Tom makes the claim that the chapter could have discussed SQL language more in depth, but supports this claim with a shallow, opinion-based rationale.

An average score on quality of claims would denote a pattern of claim making where the team supports their claims with logical, but opinion-based rationale. To score above average (score of four), teams had to show evidence of at least one instance of claims supported with logical, evidence-based rationale that referred to course content from the text or another information source such as the one below:

"I beg to differ just a little bit, Hal. It's not so much a lack of security as it is the fact that absolutely anything is hackable. Remember how the first chapter of the book discussed bits, everything is 1's and 0's to a computer? You can reverse engineer computer code, break it down to those most basic of components, so there is really no such thing as perfect security. The only sure-fire way to keep your information safe is to never share it to begin with."

Only two out of our thirteen teams scored top marks on this item, having two or more examples of logical, evidence-based rationale during their one-hour discussion session.

(RQ2) To what extent does the activity design model and differing reflective activities affect teams' improvement of collaborative discourse over time?

In refining our model, we wanted to (1) test the utility of our activity design model as a means to support the improvement of the quality of collaborative discussion processes over time and (2) determine which of two reflective procedures best facilitated sociometacognitive learning: students' ability to modify activity to meet collaborative process goals. To accomplish these aims, teams were placed into one of two individual reflective assessment conditions and a trained research assistant measured Collaborative Discussion Quality at five time points. All teams followed the activity design model, but there were two conditions for reflective activity. After each discussion session, teams assigned to condition A, future thinking, were required to score their team using the Collaborative Discussion Quality assessment and then provide a strategy they could use in the next session to improve the quality of their collaborative processes. Teams assigned to condition B, evidence, followed the same procedures as condition A with one exception: they provided evidence from the discussion to support their self-assessment ratings instead of a providing strategy to improve performance.

Altogether, the data set consisted of 125 data points. We built an ANOVA model with team Collaborative Discussion Quality as measured by an expert rater at a time point as the dependent measure. Condition was the independent variable. Time nested within Condition was a covariate. Additionally, we included Team nested within Condition as a control variable. If the manipulation supports quality at each time point, we expect a main effect of condition. If quality improves significantly over time, we expect to see an effect of time. If the improvement is different between the two conditions, we expect the slope associated with the time variable to differ between conditions.

We found Time had a significant effect in the model. The partial correlation of Time on Discussion Quality in this model was .45, p < .005. This suggests that the activity design model facilitated the improvement collaborative discussion quality over time.

The effect of Condition was also significant: F (1, 110) = 5.46, p < .05, effect size .37 standard deviations. Teams in Condition A (future thinking) had lower scores on average (M = 11.07, SD = 2.19) than teams in Condition B (evidence) (M = 11.87, SD = 2.11). The slope for Condition A was slightly higher than for Condition B, but the difference in slopes was not statistically significant when compared through a hierarchical growth model. In this analysis, both Condition and Time were significant predictors of collaborative process quality. Though teams improved on both collective information synthesis and knowledge negotiation, we found

that most of the improvement was due to students' consistent improvement with the quality of knowledge negotiation. In session one, ten teams were rated as below average on knowledge negotiation processes, but the number of teams scoring below average steadily decreased over time. By session four, four teams were below average. No teams were below average in session five. The same pattern was not true of information synthesis.

Conclusions and implications

The work presented in this paper helps to inform the design of activities that could be included as part of CSCL systems to support collective regulation and improvement of collaborative processes. Our online students were prone to similar types of dysfunctional patterns of collaborative interaction as undergraduate students in face-to-face instructional conditions (Borge & Carroll, 2010; Carroll et al, 2014). Initially, online teams were able to discuss course concepts, share opinions, and extend the ideas of others, but the diversity and quality of the claims that were made, along with verbal participation, were less than optimal.

Rather that guide students' collaborative activity during discussion sessions, we chose to provide students with reflective assessment activities. These activities articulated a model of optimal collaborative processes for collective information synthesis and knowledge negotiation. We found that this approach combined with feedback succeeded in helping students to improve the quality of their discussions over time, thus supporting the utility of the activity design model. However, we have yet to fully investigate students' perspectives of the utility of the activity and analyze their feedback to inform the model.

With regard to evaluating the two different types of reflective activities we found that asking students to provide evidence from their chat sessions to support their assessments of process quality (evidence condition) was associated with more improvement over time than asking students to provide strategies they could use to improve future performance (future thinking condition). This is interesting because we expected that requiring students to propose strategies for future discussions would facilitate behavior change and lead to more improvement, but our data does not support this claim. One explanation for the difference between reflective assessment conditions is that students may need more support when thinking about current processes, before moving onto future planning. It is possible that requiring students to provide evidence for their ratings from their discussion sessions pushed them to think more critically about how they were assessing their team and whether they understood the assessment items. In thinking more deeply about the assessment, students may internalize the assessment criteria more than they would otherwise.

We are working to incorporate our findings to inform the design of a CSCL environment with awareness affordances designed to support reflection as online students work to collectively regulate collaborative interactions. Future studies will explore how to help students improve their accuracy of assessment over time. Preliminary experimentation with automated analysis of the discussion data suggests that while machine learning models for assessment are less accurate than experts, they may be more accurate than the students, and thus it may be feasible to use this technology to support improvement in this area. Investigating how to improve this automated assessment and use it in interventions for supporting improvement in self-assessment accuracy over time is an important direction of our continued research.

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Meaning-Making in Collaborative Activity: Effort toward Coherent, but Not Shared, Interpretations of the Problem

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Abstract: In this paper we report results from a first iteration of design-based research project exploring the potential of classroom networks of handheld tablets (iPads) to support collaborative reasoning in physics. This paper examines the interpretive acts performed in the collaborative discourse of a group of physics students as enactments of personal understandings, with the goal of understanding how distinct interpretations arise and are elaborated and negotiated by collaborative groups. Specifically we focus on a case in which 'incompatible' interpretations arise, and argue that the group makes efforts after coherent, but not necessarily shared, interpretations.

Keywords: interpretation, classroom networks, handhelds, design-based research, physics

Introduction

CSCL is centrally concerned with intersubjective meaning-making: the processes by which groups of learners construct shared meaning (Suthers, 2006). Still there are various views on the relationship between individual and group meaning-making processes, and individual and group learning. Particularly, this paper looks closely at the role of individual *interpretation* of the meaning constructed in face-to-face collaborative settings. Interpretation has been conceptualized several ways in the CSCL literature. Suthers (2006) focuses on the actions that constitute interpretation-interpretations are enacted in verbal utterances, gestures, manipulations of artifacts; by acting, learners make their interpretations visible, both to their group members and to researchers. Producing an interpretation adds to the available artifacts to interpret, changing the meaning-making landscape from which the other students can form interpretations. In this way, individual contributions take up and build on one another dynamically. On the other hand, interpretations have been conceptualized as personal preunderstandings (Stahl, 2003)-specific to each student, dependent on their prior knowledge and experiencewhich become problematized, elaborated, and modified during group activity. Meaning is constructed in interaction, however, and exists in the interpersonal space. In this view, learners have (tacit or explicit) interpretations of collaboratively constructed, shared meaning. The distinction between interpretation and interpretive acts might be useful in distinguishing these views; interpretation being a personal understanding associated with an individual, and interpretive acts being the ways in which those understandings are enacted in group discourse and made visible to the group and to researchers.

Roschelle (1992) found that individuals working in groups tend to converge on a shared conception of a problem; later work conceptualized collaborative learning as the result of efforts made to maintain such a joint conception (Roschelle & Teasley, 1995). The view of interpretive acts as each building on and modifying one another lends itself to a 'gradual changes' view of the evolution of a joint problem conception. However, it is difficult to use such a lens to understand the collaborative processes behind the major, paradigmatic shifts of interpretation and understanding that are sometimes necessary to solve and understand a complex problem. This paper seeks to examine the interpretive acts performed in collaborative discourse as enactments of particular personal understandings, with the goal of understanding how distinct interpretations arise and are elaborated and negotiated by collaborative groups. Specifically we focus on a case in which 'incompatible' interpretations arise and must be reconciled.

Learning environment design

We locate this design work relative to two distinct axes of prior research. Research in collaborative learning indicates that tasks are likely to be most effective when they are sufficiently open-ended and complex to necessitate contributions from each member (Cohen, 1994), and when participants engage the task and one another in ways that sustain that variety of contributions (Barron, 2003). Relative to this axis, networked handhelds can facilitate greater communication, coordination and negotiation among peers (Zurita & Nussbaum, 2004), and expand and enrich avenues for active participation in joint problem-solving activity (White & Pea, 2011). Along an axis of research more focused on the individual learner, simulations and interactive multimedia

can be engaging and assist in complex visualization (Adams et al, 2008); contemporary personal devices such as tablet PCs offer the potential to further enrich those supports through more continual mobile access and intuitive, touch-based interfaces. One aim of this project is to design technology-supported activities that synergistically draw on both the individual and collaborative offerings of networked handhelds.

Technology

Our learning environment is designed to support groups of undergraduate physics students in making sense of the physics of mechanical waves. Each student is given an iPad Air running our iOS application: an interactive simulation of many independent mass-spring oscillators set at equal intervals along the horizontal axis. The oscillators' vertical motion is animated on each iPad when the student pushes a "play" button; the oscillators are returned to their initial positions when the student stops the simulation with a "pause" button. The initial position and direction of each oscillator can be adjusted using an interactive "unit circle" tool, a representation of the unit circle with angle markings at intervals of $\pi/16$. To adjust the position and direction of a selected oscillator, the student drags a point around the circumference of the unit circle to the corresponding phase angle.

When the phases of the oscillators are set at regular intervals, the oscillators will together form a travelling wave, the wavelength and direction depending on the phase interval between adjacent oscillators. The direction of the wave is determined by whether the phase is increasing or decreasing as you move along the x-axis. Each iPad connects to a local server that assigns each student in a group control over a subset of the oscillators. When one student makes changes to the position or direction of one of his or her oscillators, the app messages the server, which then communicates those changes to the rest of the group. When each student reruns the simulation on her own device, the initial oscillator positions are updated. Thus, in order to build a wave together, the students must coordinate the phases of their individual oscillators.

Task design

Our design is intended to encourage student interactions around concepts related to mechanical waves and wave motion. Specifically, we intend the activity to occasion talk about the concepts of phase, relative phase and phase intervals, and how these relate to observable aspects of wave phenomena such as wavelength and wave direction. In order to build a wave, the students must coordinate the phases of their individual oscillators, and performing this coordination will likely require students to take up the concept of phase, and its representation on the unit circle, as meaningful and useful to the wave-building task. Students were given worksheets with task directions. The task progression was to: 1) build a wave with a wavelength of 16 units, 2) build a wave with a wavelength of 8 units, and 3) build a wave with a wavelength of 8 units, but moving in the opposite direction.

Methods

Context and participants

The Physics 7 series at University of California, Davis is a three-quarter introductory Physics sequence for biological science majors. The sequence is unusual in that Physics 7 students spend 5 hours per week in a hybrid Discussion/Laboratory, and only about an hour per week in a traditional lecture. The goal of these Discussion/Laboratory sections is for students to engage in high-level conceptual reasoning about physics concepts, in what the course designers call "active sense-making" (Potter, 2012). Two main instructional strategies serve that goal: small group collaboration, and a focus on a small number of conceptual models. Nearly all class work is done in a face-to-face setting in groups of four to six. Additionally, the course content is structured around a relatively small set of physics models designed to focus the students' attention on the "big ideas" of Physics. In these Discussion/Lab sections students work through problems, discuss, argue, explain and make sense of physics problems. A typical class session has small groups working through conceptual reasoning activities, each group presenting their results on a shared whiteboard, followed by a whole-class discussion of the results led by the graduate teaching assistant.

Our classroom implementation of the Making Waves activity was conducted in the final course of the CLASP series, during the first two consecutive, three-hour discussion/lab sessions at the beginning of the quarter. These first two class sessions are devoted to oscillatory motion and waves. For our intervention sections, we replaced an activity in which students primarily produced and reasoned with graphical representations of waves with modified worksheets with the Making Waves task prompts. We conducted one 'pilot' session in Winter quarter 2013 with one participating class section of twelve students, and a second in Spring 2014 with four course sections (of thirty students each) using this design.

Episode selection

In a typical Physics 7 activity, the TAs walk around the classroom and interact with student groups. Many of these interactions throughout our activity sessions involved the TAs explicitly telling the students what to do to accomplish the assigned task. As we were primarily interested in supporting student-student interactions in small groups, we looked first for episodes in which students reasoned together without substantial guidance by their TA. We chose to analyze an episode in which four students reason about a strategy for changing the direction of the wave they had just built, and construct an accompanying explanation of why their strategy should work. This episode was chosen primarily because it was an instance of group members clearly enacting distinct interpretations—one group member leaves the table while the group discussion continues, then returns and offers his own, very different strategy for reversing the wave direction. Additionally, this episode was chosen in part because these students were particularly vocal and articulate about their strategies, and because each student in the group participated in the reasoning session. The selected episode is representative of the broader data set in that the strategy the students came up with the same as the other groups, but was notable in that the TA did not play a direct role in the construction of the final explanation.

Analytic approach

The goals of our analysis are to uncover the ways in which this group of students enacted distinct interpretations and subsequently negotiated those interpretations—particularly in the instance in which the interpretations were substantially different. As such enactments involve verbal utterances, gesture, body language, gaze and interactions with materials, we employed interaction analysis (Jordan & Henderson, 1995), in which repeat viewings of the selected episode allowed us to make sense of the interaction at both the "macro" and "micro" interactional levels. We first transcribed the episode fully, additionally annotating hand movements used in communication, beginning at the 'problem statement' by the TA and ending when the group had changed the topic of conversation. Within the video segment and using the transcript, we then identified for further analysis three episodes in which distinct interpretations arose.

Results

The selected episodes featured a group of four students: two men (J and S) and two women (A and B). The episode took place after the group had just successfully constructed a wave with a wavelength of 8 units, pointby-point. Some of the group's wave-building activity prior to the selected episode is relevant to understand it: as this was a group of four, their wavelength was divisible by the number of people in the group. This had the effect of J's oscillators each alternating phase between 0 and π —and because of this coincidence, he found during the initial wave building task that these two phases each corresponded to his oscillators each being at the "equilibrium point," in the y = 0 position. He noted aloud that both phases corresponded to the same position, but that the difference between a phase of 0 and a phase of π is in which *direction* the oscillator is going—zero corresponding to upward motion, and π corresponding to downward motion through equilibrium.

The selected video segment began as J left the group for a trip to the restroom, and the TA asked the remaining three students how they would reverse their wave's direction. The episode has three parts: in Part One, the group (S, A and B) constructed an initial strategy and accompanying explanation of why that strategy should work; in Part Two, J had returned and proposed an alternative strategy. In Part 3, the full group discusses a reinterpretation of the original strategy.

Episode one: A joint production without shared knowledge

As they finished building their first wave, J left the table for a trip to the restroom, and the other three students remained at the table. The TA approached the group and prompted them with the next question from the activity sheet, asking how they would change the direction of the wave they had just built.

TA:	So we decided it's moving left, right?
B:	Mh-hm.
A:	Yeah.
TA:	How do you guys think you could make it move right?
A:	What!
TA:	How could you make it move to the right instead?
B:	Change the pha:se/? <tentative></tentative>
TA:	I mean yes, but [everything is changing the phase, right.

A:	[Everybody would shif:	t<< go
	backwards>>.	
S:	[Yeah.	
TA:	[Yes:[
A:	[< <like [we="" all="" go<="" going="" instead="" of="" th="" this="" way,="" would=""><th>o that way.>></th></like>	o that way.>>
TA:	[Why would tha	t work?
A:	Cau:se	
S:	Cause you're reversing the direction of you're oscillation . So initially, one of these points either starts[reversing the
	Γ	
A:	<elevated></elevated>	oing u:p
A: S:		oing u:p
	<elevated></elevated>	oing u:p
S:	<elevated> like I'm assuming this starts [up.</elevated>	oing u:p
S: A:	<elevated> like I'm assuming this starts [up. [oh: <elevated></elevated></elevated>	
S: A: S:	<elevated> like I'm assuming this starts [up. [oh: <elevated> Or down. If you reverse that</elevated></elevated>	ing you're going to

The TA initially posed the question to the group as "how could you make it move to the right instead [of left]?" B's initial suggestion to "change the phase" was tentative, as indicated by her uptalk and elongation of the word "phase." Her hesitation suggests that she suspected that the strategy would involve phase, but did not yet have a definite picture of how 'phase' related to the making the wave "move to the right." B's suggestion was rejected by the TA as not incorrect ("I mean yes") yet not satisfactory ("but"), and in particular, too general ("everything is changing the phase, right?").

S and A then jointly constructed a chain of concepts linking *phase* to *wave direction*. A first posited that everybody would "go backwards," and elaborated this meaning with "go this way," coupled with a gesture of a smooth rotation motion along the unit circle. The TA immediately affirmed this strategy, but asked for an elaborated explanation ("why would that work?"). A began an explanatory response ("cau:se...") but S filled in the content, explaining that it would work "cause you're reversing the direction of… you're reversing the oscillation." As A did earlier, he related his explanation as a modification to the group's prior activity ("initially, one of these points starts up" ... "if you reverse that"). He then continued to relate "reversing the oscillation" to "changing" the wave direction. S's and A's talk is intertwined in this segment, A saying "oh:" and using elongated and elevated tones to indicate a realization or new understanding, while also implying her acceptance of S's contribution. This strategy, and accompanying explanation, was a socially distributed production comprising contributions from each of S, A and B.

What is interesting about this particular exchange is that the two students, S and A, appear to have been talking about two physically different situations—in particular, two distinct interpretations of the relationship between going "backwards" and the oscillators' motion. A appeared to be talking about the effect on the *direction* of motion of each of the oscillators, while S was talking about the effect on their *position*: A used the phrase "going up," while S used just "up." While these may be subtle differences in language use, they are accompanied by significant differences in gestural activity. A showed a smooth motion clockwise around the unit circle, then mimicked going up. S didn't refer to the unit circle in his explanation, but continued the verbal explanation (beginning with repetition of A's "cause") of A's "go backwards" strategy, mimicked oscillation with pinched fingers moving up and down, then as he said "starts up" he moved his pinched fingers vertically upward, paused, then as he said "down," pulled his hand backward and moved his pinched fingers to a lower position. He continued "if you reverse that," repeating this up-to-down motion, "you're going to change the way," mimicking waves in place, "everything else moves," with a rightward-moving flat hand, indicating a rightward-moving wavefront. His gestures suggest that he interpreted "reversing the oscillation" not as reversing each oscillator's direction, as A did, but reversing their initial positions from "up" to "down." S even stopped his initial explanation mid-sentence to repeat it specifically omitting the word *direction* ("Cause you're reversing the direction of... you're reversing the oscillation"), suggesting that *direction* wasn't relevant to his interpretation.

This further suggests a possible difference in interpretation of the verbal phrase "go backwards." A's initial "go backwards" was accompanied by a *smooth* clockwise motion around the unit circle. Coupled with her focus on changing the oscillators' *directions*, this may suggest that she took *going backwards* to mean that each point should progress, as time goes on, clockwise on the unit circle rather than counterclockwise (this would indeed have reversed the wave direction). On the other hand, S did not gesture referring to the unit circle (he took up the explanation from there)—yet his emphasis on *changing position* would be consistent with an interpretation of "going backwards" to mean a reversal of their initial wave construction strategy: to now subtract phase as each person sets their points, rather than to add phase with every point.

Episode two: Making two interpretations coherent

At the end of the above segment, J returned from his trip to the restroom, and S asked him how he would change the direction of the wave:

S:	How do you think you'd change the direction how do you think you'd change the direction of the wave?
J:	Change the direction it's like, oka:y (turning on iPad and looking down at it) well you change the equilibrium points from right you change the zeros when you change the equilibrium points you like you flip the uh (looks up from iPad at A) wait what was zero, you'd flip that to pi? Right, and everything? And all the two Pi equivalents right?
A:	I think so: it's just the direction also flips with it. Yeah.
S:	[Yeah. Yeah, yeah.

As J thought aloud in the beginning of this sequence, his reasoning seemed to hinge on the word "change" ("change the direction... you change the equilibrium points... you change the zeros... you change the equilibrium points, you flip the..."). "Change the direction" appears to have been a verbal cue for J, bringing about a recollection of his prior experience during the wave-building activity of "changing the direction" of the "equilibrium points." J made this prior experience relevant to the current conversation through his repetition of the phrase "change the direction," first in reference to the wave, and then in referring the "equilibrium points." He then made the "change" more specific by transitioning from "change" to "flip" ("when you change the [direction through the] equilibrium points... you flip the [zeros to Pis]").

While this contribution also related the wave to the individual oscillators to the unit circle, it did so in a way that was inconsistent with the group's already proposed strategy. According to J, the group would take each of the points along their existing wave and adjust the phase on the unit circle to the "equivalent point"—where the position was the same but the direction of motion was reversed. This would indeed have worked. The strategy constructed by the other students, however, was to redo the point-by-point building of a wave, this time going clockwise on the unit circle. This strategy also works, and ultimately differs from J's only by an initial phase factor. However, the processes being suggested for building the reversed wave are substantially different, and not obviously compatible.

Now we focus on how the group responded to these distinct strategies. In response to J's newly suggested strategy, A began with a statement of agreement ("I think so...."), elongating the "so" to hold her conversational turn as she thought. When she spoke again, she began with "it's just," then followed it with a point of similarity between her interpretation and J's ("it's just the direction *also* flips", emphasis mine). This suggests that the effort she was making while silent was to reconcile J's "flipping points" with her own interpretation of the original group strategy by finding ways in which they were, effectively, the same. She enacted this reconciliation both verbally and gesturally, by repeating J's use of the word "flip", and modifying her original "direction" gesture to end in a "flipping" motion (see Figure 1).

A and S jointly accepted this connection between the strategies: as she said "Yeah," she gestured toward S with an open hand, palm upward, referring to their previous exchange, that (in A's interpretation) meant that "reversing the oscillation" was sufficient to "change the [wave] direction." A's contribution here, gesturally "flipping the direction" of the oscillator and then gesturing to S indicates that her interpretation of the initial explanation was indeed focused on flipping each of the oscillator directions, not their positions. While S did not seem to be interpreting direction as meaningful before, he nevertheless accepted here that flipping the direction was in accordance with the explanation of their previous strategy.



Figure 1. "(a) It's just (b) the direction also (c) flips with it. (d) Yeah."

Episode three: Purposeful reinterpretation

The group had now introduced two qualitatively different strategies: "going backwards," which required the group to restart their coordination efforts, and "flipping points," which involved taking each point as it is in the leftward-travelling configuration, and transforming it by "flipping" it to a new position. J next attempted to re-express his strategy:

J:	So we all need to find an equivalent point that's like would you not move the dot, would you want it the same area, but like what did he say, like what did you guys figure out?
[A responds, J a	sks her to repeat.]
A:	Like you know how when we did our first one? You were here and like oh she was there and he was there and I was here Now we'd have to go We have to go the other direction.
J:	Is there a way to think about it mathematically though?
A:	That's what I was think- the negative Pi/? Is there a way/?
B:	This would be pi/2 instead of 3Pi/2, but
S:	Yeah
B:	Negative?
J:	Like I'm saying if you shift that over
B:	Isn't that math though, isn't it like this way is positive but if you go this way it's negative?
A:	Negative. So in a way it is mathematically correct?
S:	Yeah.
B:	like it'd be negative pi/2?
J:	OK so if we we added pi/8 right? So if we subTRACT pi/8 from the equilibrium point
A:	now you're going in the other direction.
B:	negative pi/8
A:	Now it makes sense.
S:	So we shouldn't think about it as flipping points , but we should think about it as going the opposite direction on the unit circle .
A:	which makes it negative.
S:	Because waves behave he says wave behaves like a sine curve. Sine curve is like choo, choo it's oscillating. So we oscillate the other direction
J:	that makes a lot more sense.

J attempted to elaborate his "flipping points" strategy, suggesting that they each needed to find "equivalent points" (positions along the unit circle) that would keep their "dots" in the same vertical positions, but change their directions of motion. (This strategy would indeed have worked.) However, A provided no

positive feedback while J made this contribution—no indication she shared his interpretation. A then related her strategy to J without taking up any aspect of his "equivalent points" idea. This effectively suppressed J's "equivalent point" idea, as they didn't discuss the way in which this strategy might maintain the "equivalence" of the points, and there was no further effort to reconcile these two strategies.

As A related the strategy, she reminded J of the group's original strategy ("you know how like before when we started") and replayed it gesturally, touching her finger to each point along the unit circle, progressing counter-clockwise at equal intervals ("I was here he was there and you were here"). She then switched to the new strategy in contrast by switching tense ("we would have to go") and replaying her motions along the unit circle but this time moving clockwise ("you are here... I'm here"). In doing so, she ued the group's prior activity to explain the new one to J. She summarized the new strategy ("go this way"). J then, without reference to any details of what A had just said, asked if there was a way to think about A's strategy mathematically. This contribution is noteworthy in that it was a shift from "tool talk" to "concept talk"—rather than being about the procedure of building a specific wave, it was about a particular way to understand that procedure. The group then tried to come up with a way to think about their strategy mathematically, their discussion initially centered on the negative/positive distinction between going clockwise/counter-clockwise on the unit circle. Then, J's mathematical interpretation of the strategy as *subtracting* in contrast to the previous strategy of *adding* became a new explanation for why A's strategy should work. Adding/subtracting $\pi/8$ likely had a higher degree of relation to the strategy A had gesturally enacted than positive/negative.

Saying "now you're going in the other direction" with a tone of relief, A accepted J's interpretation. Her gesture coinciding with the word "other" is interesting—instead of mimicking direction on the unit circle or the direction of an oscillator as she had done before (or taking up S's gesture for the direction of the wave), she summed it all up with a "hand flip" gesture that simply emphasized the word "other." She then gestured "palm up" at S again (the first time she did so, she was referring to flipping the oscillator directions being sufficient to reverse the wave direction). Now repeating that gesture, she effectively completed the explanation. This was in line with A's (apparent) interpretation that the essence of the wave reversal strategy was to make everything (unit circle, then oscillator, then wave) go the *other* direction. S took this up and positioned "flipping points" and "going the opposite direction" as two different ways of thinking about this. However, he did not adopt J's "adding/subtracting" language—he simply reiterated the initial idea about going around the unit circle, now emphasizing "other" as A did, but accompanied by a different ambiguous gesture.

Discussion

The analysis presented highlights the need to attend to distinct, personal interpretations in accounts of meaningmaking. In Stahl's (2003) sense, meaning is shared because it is constructed through an interpersonal process of mutual recognition: a reference to something takes on a function in the ongoing discourse and therefore *means* something to the participants. However, trying to understand the group's discourse through this lens is problematic. For example, the initial explanation co-constructed by S and A made use of the phrase "go backwards." However, "go backwards" had two distinct functions in the activity as interpreted by S and A, as evidenced by their distinct gestural activity: either reversing oscillator position, or reversing oscillator direction. Thus it was not that there were two interpretations of the meaning of "go backwards," but that the phrase itself had two meanings, which were not in any useful sense *shared* by S and A. An alternative to a focus on individual interpretations of shared meaning might be found in Greeno and van de Sande's (2007) theory of perspectival understandings, which posits that individuals have personal perspectives – points of view that foreground one particular set of concepts and relationships between them. In this sense, A and S took different perspectives on the relationships between "going backwards" on the unit circle, oscillator position, oscillator direction, and wave direction, without requiring that each of these concepts had a meaning shared by the participants.

The analysis presented also highlights the ways that attention to individual interpretations can help researchers make sense of the interpretive acts by which the group accomplishes meaning-making. Taking the view proposed in Suthers (2006) that intersubjective meaning-making involves the joint composition of interpretations— the producing, taking up, modifying or elaborating a set of shared verbal, gestural or material artifacts— we can interpret A's utterance in Episode Two as taking up both J's statement about "flipping points" alongside her earlier idea about changing directions, and connecting these two conceptually. However, without a focus on individual interpretations it is difficult to see why A might have made that particular connection, or why it was A who made it. Attending to interpretations as personal understandings, her contribution represents an effort to reduce J's proposed idea to something consistent, or coherent, with her own currently held interpretation in which oscillator direction change was important. Additionally, A may have played this reconciliation role because her interpretation enabled her to see potential connection with J's. S's interpretation,

on the other hand, in which *position* change was important, may have made it more difficult for him to make a connection to "flipping points"— an action which changes the direction, but not the position, of the oscillators. Lastly, attention to interpretations helps make sense of J's attempt to shift to a mathematical interpretation in Episode Three. In J's own words, he was looking for "a way to think about that"— not for new information, or a "missing" artifact, but a new *organization* of what was already available to him— a new way to interpret the concepts relevant to their wave building activity.

While these students achieved a degree of intersubjectivity sufficient to successfully accomplish the wave building and reversal tasks, and to collaboratively construct an explanation of their reversal strategy acceptable to their TA, they did so without ever sharing interpretations of their activity. To some extent, the students' conceptions of the problem of building a wave, or reversing its direction, must have converged—they could reliably, successfully build arbitrary waves together as a group by the end of the activity, and could not at the beginning. However, their interpretations-- specifically related the conceptual mechanisms of direction reversal-- did not converge, either during the wave-building activity or during the subsequent discussion. This suggests that conceptual convergence, in Roschelle's sense, may pertain to the more pragmatic features of the problem at hand, on which the group must agree to coordinate their actions-- while *interpretations* may be of the underlying conceptual structure of the problem, which need not be shared to succeed. It is an interesting future research question how these two layers relate to one another, and co-evolve in discourse.

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The Development of Productive Vocabulary in Knowledge Building: A Longitudinal Study

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Abstract: We report a longitudinal study on the development of 22 students' productive vocabulary in knowledge building from Grade 1 to 6. Vocabulary growth was assessed based on the student discourse in Knowledge Forum, an online community space designed to support Knowledge Building. Analysis of lexical proficiency based on Lexical Frequency Profile and P_Lex indicated significant growth in productive written vocabulary, especially for words beyond the first two 1,000 word lists. By tracing the growth of vocabulary extracted from specific word lists, we found that the growth rate for different types of words varied across each year but correlated with each other. Correlation analyses between these lexical measures and Knowledge Building behavioral indicators revealed that note revisions are the strongest predictor of vocabulary growth rate, whereas note reading is related with lexical proficiency measures.

Keywords: Knowledge Building, literacy development, productive vocabulary, CSCL

Introduction

Language acquisition is considered a major milestone in child development and plays a critical role in shaping the child's participation in everyday practices. For example, the child's lexicon shares an interdependent relationship with school learning and performance. Studies in the classroom have shown that word knowledge plays a critical role in verbal and listening skills, reading comprehension, and learning of new concepts (e.g., Biemiller, 2005; Cunningham & Stanovich, 1997; Stahl, 1991; Steahr, 2009). Additionally, the more words the student knows, the easier it is for them to access new resources and learn more (Stahl, 1991). Over the last few decades, a body of research in literacy education has been devoted to improving student learning and reading through explicit vocabulary instruction (for a review see Rupley, 2009). However, there is evidence that explicit vocabulary instruction leads to a decontextualized understanding of words. For example, teaching new vocabulary through dictionary definitions and spelling lists can lead to misuses of the true meaning of words; rather, learning new words through emergent use in authentic contexts can support a more holistic understanding of them (Miller & Gildea, 1987).

Recognizing the limitations of explicit vocabulary instruction, developmental psychologists propose a social-pragmatic view of language development (Akhtar & Tomasello, 2000), which argues that language acquisition is driven by social interaction and the child's need to connect with others. In other words, the child's lexicon is acquired through social experiences and conversational interactions wherein they are exposed to language (Hoff, 2002). Words and sentences do not exist as islands by themselves; thus, explicit vocabulary instruction that presents word definitions and exemplary sentences as self-contained "pieces" of knowledge would not be sufficient (Brown, Collins, & Duguid, 1989). Sociocultural theorists further add that child development, which extends across social, conceptual, linguistic, and cultural competencies, must be understood within the cultural context that the child develops (Vygotsky, 1978; Hedegaard, 2009). According to this perspective, learning is a social and collaborative process, and classroom environments must support peer-to-peer interaction (Hakkarainen, Paavola, Kangas, & Seitamaa-Hakkarainen, 2013). Integrated educational contexts for literacy allow students to participate in meaningful activities related to novel and challenging words through a variety of encounters and are effective for promoting depth of world knowledge, writing quality, and vocabulary expansion (Stahl, 1991). Benefits have been shown from the earliest grade levels of engaging students in authentic settings for vocabulary learning (e.g., Juel, 2006).

Knowledge Building (KB; Scardamalia & Bereiter, 2006), a principle-based pedagogy that engages students directly in sustained creative work with ideas, provides such a context for vocabulary development. Knowledge Building is "productive work that advances the frontiers of knowledge as these are perceived by a community" (Bereiter & Scardamalia, 2003, p. 1370). Knowledge Forum (KF)—technology designed to support Knowledge Building—immerses students in literate environments extensible to the broader world on the Internet and beyond. It aims to optimize opportunities for knowledge creation, mirroring conditions of the

surrounding open, innovation-driven, knowledge society—a complex world of ideas requiring that users create knowledge out of information fragments. In Knowledge Building classrooms, all students take collective responsibility for generating and advancing ideas that "live in the world"—most immediately, the public community knowledge spaces of Knowledge Forum, where efforts to advance the frontiers of their community knowledge require continuous reading, writing, and multimedia productions to contribute and improve ideas. Students read each other's entries, search for information to answer questions, design and report experiments, and so forth. Conceptual advances are mirrored in vocabulary growth in online and offline exchanges between students, with vocabulary advances appearing as a by-product of their knowledge work (Sun, Zhang, & Scardamalia, 2008). The Knowledge Building proposition is that immersion in complex literate worlds from early ages of schooling will lead to advances in both basic and advanced competencies. This hypothesis has been tested in previous studies, but within a shorter time frame (Resendes, Chen, Acosta, & Scardamalia, 2013; Sun, Zhang, & Scardamalia, 2008).

Knowledge Building is compatible with the social-pragmatic and sociocultural perspectives on how the social environment plays a crucial role in facilitating the acquisition and productive use of new words. The current study aims to explore the phenomenon of vocabulary growth within a student cohort across the elementary years. Such longitudinal studies of the development of the productive vocabulary are almost non-existent (Laufer, 1994), needless to say its scarcity in the Computer-Supported Collaborative Learning (CSCL) context. Of equal importance is future work to connect vocabulary development and the advancement of community knowledge in CSCL, as well as to elicit lexical measures to assess productive work with ideas in CSCL. Our major research questions concerning the development of productive vocabulary in Knowledge Building are:

- 1. How did students' lexical proficiency, as indicated by their written discourse in KF, change over the span of six years?
- 2. Did the rate of productive vocabulary growth remain consistent over time? Which words were used most frequently for each year?
- 3. To what extent was productive vocabulary growth related to students' Knowledge Building behaviours?

Methods

Participants and the knowledge building context

The participants were a student cohort of 22 students from the Dr. Jackman Institute of Child Studies (JICS) of the University of Toronto, where Knowledge Building pedagogy and technology has been used extensively for over a decade. Indeed, JICS has been highlighted as a school that continuously engages in Knowledge Building practices, due to sustained collaborative efforts made by its teachers, principals, and students (Zhang, Hong, Scardamalia, Teo, & Morley, 2011). At JICS, Grades 1 to 4 are taught in separate classes, and Grades 5 to 6 are taught in mixed classes. Each class is taught by one teacher, so students were taught by 5 different teachers in total. The students started Grade 1 and finished Grade 6 at the same time; however, two students left the school before Grade 4 and five students left before Grade 5.

Over the course of six years, students in the present study assumed collective cognitive responsibility to improve their ideas (Scardamalia, 2002): They shared the consistent goal of advancing their collective understanding about authentic problems they cared about through face-to-face discussions and online interactions in KF. They carried out explanation-seeking discourse propelled by their collective efforts to improve their ideas through various means, such as observation, experimentation, and constructive use of authoritative sources. A detailed account of classroom dynamics is beyond the scope of this article, but can be found in the Knowledge Building literature (e.g., Scardamalia & Bereiter, 2006; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). The student cohort in the present study examined topics in: science, such as "Butterflies," "Invertebrates," "Ecology," "Rocks and Minerals," and "Astronomy"; engineering, such as "Structures" and "Toys That Move"; and social science, such as "Medieval Times" and "Canadian Issues."

One important component of students' Knowledge Building work was their extensive use of Knowledge Forum (KF), an online community space for them to document ideas. Students wrote extensively about their ideas, collectively making sense of difficult concepts, building coherent explanations, and carrying out "metadiscourse" (Resendes et al., 2013). While Knowledge Building discourse took place in multiple media, KF served as the central workspace for idea development. During face-to-face discussions, students would constantly refer back to artifacts, such as texts, drawings, and videos in KF and would return to KF afterwards to

revise their notes. As a result, reading and writing in KF is a meaningful literacy practice and an integral aspect of Knowledge Building (Sun, Zhang & Scardamalia, 2008).

Data Sources and Analyses

The primary data sources in the present study were KF log data produced by the participants over six years. The dataset mainly included: (1) students' KF *notes*, as well as their metadata, such as time, title, view, and authors; and (2) students' activity log, which involved three types of actions—*reading*, *creating*, and *modifying* a note.

To study the longitudinal development of students' productive vocabulary, our analysis focused on a set of established lexical measures and their changes over time. KF notes were exported and grouped by school year. The following lexical measures were computed for each unit of analysis (i.e., KF notes produced by each student in each school year):

- (1) Lexical richness measures. We first counted the total word tokens and word types (i.e., unique words) produced by each student each year as two basic measures of lexical richness.
- (2) Lexical Frequency Profiles. Vocabulary proficiency can be measured in various ways. Lexical frequency profile (LFP) is a quantitative index proposed by Laufer and Nation (1995) to measure the vocabulary richness of a text based on its proportions of frequent versus infrequent vocabulary. The underlying assumption of LFP is that "a large number of infrequent words would make a text more difficult to understand" (Laufer, 2013, p. 1). Based on this assumption, a student's vocabulary proficiency can be inferred from the percentage of frequent and infrequent words they use in their written text. LFPs were built for each student in each year, based on three word lists from a software program developed by Paul Nation: first 1000 word families, second 1000 word families, and the Academic Word List (Coxhead, 2000). A student's LFP was presented by percentages of words from these three word lists.
- (3) P_Lex. Recognizing LFP's ineffectiveness with shorter text—text shorter than 200 words in particular (Laufer & Nation, 1995), Meara and Bell (2001) created another measure for vocabulary proficiency, P_Lex, which was claimed to work well for text as short as 90 words. This measure is based on the same assumption as LFP, (i.e., the use of infrequent vocabulary indicates higher proficiency). However, P_Lex differs from LFP on how vocabulary proficiency is calculated and represented. To calculate P_Lex of a piece of text, we first divide the text into segments of 10 words. Then, for each segment, we count "infrequent" words beyond the first 1000 word families. For an imagined paragraph containing 108 words, we may get a vector: [0, 0, 2, 1, 1, 1, 2, 1, 0, 0]. Then, we would feed the counts of each possible value (i.e., {0:4, 1:4, 2:2, 3:0, ... 10:0}) into a Poisson distribution model. A λ (lambda) coefficient in the Poisson distribution model (ranging from 0 to about 4.5) is computed to represent the lexical proficiency represented by the text, with a higher lambda score corresponding to a higher proportion of infrequent words (for details see Meara & Bell, 2001).
- (4) Rate of vocabulary growth. Both LFP and P_Lex are solely concerned with the makeup of frequent versus infrequent vocabulary in texts and do not provide information about the growth of productive vocabulary size. Thus, for each student we also traced new vocabulary that appeared during each year. Using the same word lists as those used for LFP, we further distinguished frequent and infrequent vocabulary acquired by each student in each year. This analysis would help us pinpoint the words students acquired each year and the distribution of these words in different word lists.

To determine whether there were changes within these lexical measures across the six years, Mann-Kendall tests of trends and multivariate analysis of variance (MANOVA) was further conducted on each measure. Meanwhile, to investigate the relationship between lexical development and Knowledge Building activities, correlation analyses were conducted between the frequencies of Knowledge Forum behavioural indicators, such as reading a note, creating a new note, and modifying an existing note, and the lexical measures describe above. Additional correlation analyses were conducted among lexical measures for validity purposes.

Finally, in order to uncover the context in which vocabulary learning occurs, we tracked a number of "difficult" words identified from students' entries. Content analysis of related discourse was conducted to shed light on the interpretation of aforementioned analyses.

Findings

Note writing and reading across six years

Table 1 shows the number of notes written, modified and read per student during six years. Over the six years, the average student created 88.67 notes, revised 63.43 notes, and read 601.48 notes, indicating substantial

literacy practices in Knowledge Forum throughout the years. However, there were considerable variations across the years and among students, which were also found in previous studies (Sun, Zhang & Scardamalia, 2008). At the class level, students were most active in Grade 3 and 4, while in Grade 6 their KF activities dropped to the lowest. This drop could be partially attributed to the increased adoption of other learning technologies when students entered higher grades, as reported by teachers. At the individual level, detailed analysis uncovered substantive variations potentially linked to individual differences worth further investigation.

Activities	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Reading	63.10 (24.9)	73.95 (25.1)	182.00 (94.5)	235.63 (115.5)	67.38 (52.1)	48.17 (41.0)
Creating	15.10 (5.2)	18.43 (9.3)	19.71 (10.6)	21.74 (8.8)	12.85 (8.9)	10.17 (7.3)
Revising	12.33 (4.3)	9.33 (4.2)	14.76 (9.7)	18.89 (8.5)	8.38 (6.1)	8.25 (6.3)

Table 1. Mean and standard deviation of student activities in Knowledge Forum

Vocabulary use reflected by Lexical Frequency Profiles and P Lex

Table 2 presents the total word tokens and total word types (unique tokens), two lexical richness measures, in each year. Regardless of fluctuations across years, Mann-Kendall trend tests on both measures were significant ($\tau = 0.18$, p < .01 for both), indicating a trend of increase of produced tokens and unique tokens over the years.

Table 2. Mean and standard deviation of Lexical richness of student writing

Measures	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Total tokens	208.10 (115.4)	159.48 (129.6)	114.48 (108.3)	176.53 (119.3)	498.38 (394.9)	366.23 (274.2)
Total types	98.90 (38.0)	72.38 (39.5)	65.10 (32.6)	85.21 (41.8)	146.69 (75.8)	122.85 (43.1)

Table 3 presents the P_Lex scores of student writing in each grade. A Mann-Kendall test confirmed a significant trend of increase, $\tau = 0.24$, p < .001 (see Figure 1). Repeated measure ANOVA also revealed significant changes in P_Lex over the six years, F(5, 82) = 12.2, p < .001, $\eta^2 = 0.42$. However, it should be noted that P Lex dropped in Grade 6, which corresponded to the drop of writing activities in Grade 6.

While P_Lex provided a more robust measure of lexical profile in this specific context, lexical frequency profiles offered a more detailed depiction of the composition of vocabulary in student writing. Table 3 reports the lexical frequency profiles of students across the six years. Trend analysis revealed a significant decrease with the percentage of the first 1,000 words, $\tau = -0.24$, p < .001, and a significant increase with the percentage of words not in the lists, $\tau = 0.27$, p < .0001. However, no trend was discerned from the percentages of the second 1,000 words and the Academic words.

Table 3. Mean and standard deviation of word tokens, types, lexical frequency profiles, and P_Lex in each student's notes across the six years

Measures	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
P_Lex	1.07 (0.3)	1.23 (0.4)	1.95 (0.5)	1.77 (0.7)	1.76 (0.4)	1.37 (0.4)
% 1st 1,000 words	89.2% (2.9%)	87.1% (3.2%)	80.6% (4.4%)	82.2% (7.1%)	82.4% (3.8%)	86.1% (3.7%)
% 2nd 1,000 words	4.21% (2.5%)	6.43% (2.4%)	6.76% (2.7%)	6.82% (2.8%)	4.47% (2.2%)	1.53% (2.7%)
% Academic words	2.31% (1.1%)	0.54% (0.9%)	4.50% (2.7%)	2.80% (1.8%)	1.35% (1.1%)	2.72% (1.8%)
% Other words	4.28% (2.7%)	5.96% (3.0%)	8.14% (3.3%)	8.23% (6.1%)	11.8% (3.5%)	6.77% (3.0%)

Vocabulary growth across years

While P_Lex and LFP helped us determine the quality of student writing based on the percentage of different kinds of words, we were also interested in examining students' vocabulary growth based on the productive use of new words, so we traced vocabulary use for each individual student, focusing on new words they picked up in each grade.

Text mining of the entire collection of student notes over the six years revealed the following overall distribution of terms: 1091 first 1,000 words, 331 second 1,000 words, 105 academic words, and 635 words not in these three lists. We then traced each student's acquisition of words in these four lists in each year. As presented in Figure 2, the growth of word types from these four lists of words were uneven. First of all, in each year most new words acquired by students were from the first 1,000 word list. Noticeably, the growth rate of the

first 1,000 words was consistent across years, whereas the Academic words and words out of the lists grew more rapidly in Grade 5 and 6. Mann-Kendall tests confirmed these trends—the first 1,000 words: $\tau = -0.16$, p < .05; the Academic words: $\tau = 0.12$, p = .08; words out of the lists: $\tau = 0.26$, p < .001. No significant trend was found with the second 1,000 word list.

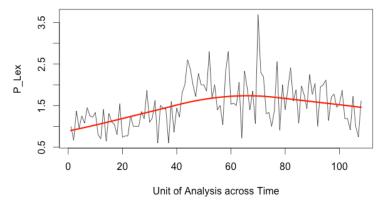


Figure 1. Trend analysis of P_Lex

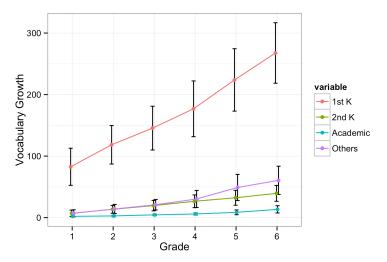


Figure 2. Growth of productive vocabulary over the six years

Relationship between vocabulary growth and KB interactions

Table 4 presents the results of correlation analysis of lexical measures and Knowledge Building measures (i.e., note reading, writing, and revisions). First of all, lexical proficiency measures (i.e., P_Lex and percentages of four different word categories) were not significantly correlated with the total numbers of word tokens and word types, implying that the lexical proficiency measures we used were not significantly affected by the length of student writing. Meanwhile, P_Lex was negatively correlated with the percentage of the first 1,000 words (r = .75, p < .001) and positively correlated with the percentages of words from the other three lists. These results confirmed the validity of using these measures to assess lexical development of students in the present study.

Second, the number of total word types was correlated with note writing (r = .29, p < .001) and note revisions (r = .42, p < .001). In addition, the vocabulary size indicated in students' six years of writing was found significantly correlated with all KB behaviours: reading (r = .55, p < .01), writing (r = .81, p < .001), and revisions (r = .77, p < .001). These correlations indicated that students who write and read more in Knowledge Forum are likely to demonstrate greater growth in productive vocabulary. Interestingly, note modification appeared to be the most significant predictor for vocabulary growth—more strongly correlated with the yearly growth rate of vocabulary (r = .35, p < .001) when compared with the other two KB measures. This finding revealed a potentially fruitful linkage between idea improvement in Knowledge Building, indicated by note revisions, and vocabulary development. Connecting with individual variations identified earlier, it would also be

worth further investigating whether there were any student-level background variables affecting both Knowledge Building behaviour indicators and lexical measures.

Finally, we found vocabulary growth in all four word categories positively correlated with each other, which suggests that basic and advanced vocabulary may have developed in tandem throughout the years, regardless their different growth rates in each year.

Measures	1	2	3	4	5	6	7	8	9
1. Word tokens	-								
2. Word types	.85***	-							
3. P Lex	.08	.09	-						
4. 1st 1,000 words	.00	.04	75***	-					
5. Academic words	12	07	.27***	36***	-				
6. New words used	.80***	.94***	.04	.09	11	-			
7. Note reading	.07	.17*	.16*	15†	.22**	.07	-		
8. Note creating	.15†	.29***	.08	01	03	.23**	.62***	-	
9. Note revision	.23**	.42***	.11	02	.07	.35***	.69***	.79***	-

Table 4. Correlation analysis of lexical measures and KB behavioral indicators

Note. $\dagger p < .10, \ast p < .05, \ast p < .01,$ p < .001

Examples of integrated practice for literacy in knowledge building

While Knowledge Building discourse itself represents a natural literacy practice, we were still interested in dialogues specifically focusing on acquiring new vocabulary. Content analysis of student discourse identified plenty of such examples. In correspondence with one lower level of vocabulary learning, one cluster of examples could be best described as "definition seeking" discussion. For example,

Student A: I need to understand: what is *velocity*? Student B: Speed.

In this example, Student A might had incidentally heard the new word *velocity*, and the conversation between him and Student B focused on the definition of this new concept. Such definition-seeking conversation can extend from one term to another, and could be fruitful for vocabulary learning. As another example,

Student C: What is *horizontally*? Horizontally is sideways. Vertical is up and down. Student D:

When Student D attempted to explain the definition of the adverb horizontally, they used the adjective form of its antonym. In this case, students were exposed to rich morphosyntactic environments for learning new words and word families.

In other cases, the definition of a word could not be easily attained; rather, meaning was achieved by piecing together snippets of the definition contributed by more than one student. Take the following conversation for example, neither Student F or G's notes alone provides an accurate definition of *claymore*, but each contains specific information about this vocabulary.

Student E: What is a <i>claymore</i> ? My theory is that it is a type of [pottery] whee	1.
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Student F: I think a *claymore* was a type of big expensive sword that only the richest nobles or "earls" owned.

Student G: My Theory [is] its a very big Scottish [sword].

The second type of literacy practice could be characterised by "active use of vocabulary" with evolving meaning. In this case, students did not explicitly seek the definition of a word and were capable of using it in specific contexts. However, by continually engaging with a concept, students were able to construct and reconstruct the scientific meaning of it over an extended period of time. One interesting example from the student discourse was the concept of "gravity." In the Water Cycle unit during Grade 1, students mentioned the role of gravity in the formation of rain: "Then the water droplets make clouds and when the clouds get too heavy with water droplets it can't hold it any more so the gravity pulls all the water and it rains!" Another example: "My theory is that it's all about gravity. The groundwater stays down by gravity!" Then, in the engineering unit about Flight, students were engaged with gravity from a different angle: "Because the plane is so big and heavy it is hard to reduce gravity because gravity can be taken away better if there are lighter, stronger materials." It was not until the Astronomy unit in Grade 5/6 when students started to clearly articulate the concept of gravity:

Student H:	How does <i>gravity</i> work? Is it a force in the ground that pulls you down or something in the air that pushes you down?
Student I:	I think gravity comes from the core of the Earth or the core of other planets.
Student J:	How does gravity work in the middle of the earth?
Student K:	Gravity is: the downward pull of the earths <i>gravitational</i> field. The more <i>gravity</i> pulling an object the more the mass of the object is.
Student L:	I need to understand: first you say that you think that you would weigh more on Jupiter because it has more <i>gravity</i> and then you say that you think that you would weigh less on Pluto because it's farther away from the sun. Are these two different theories about how much you weigh on a planet?

These conversations highlight students' various conceptions of gravity, as well as the gradual conceptual change underlying their collective discourse. Over the course of six years, even though few explicit efforts were made to define gravity, students were able to use this term in meaningful ways to support explanations in their Knowledge Building work.

In summary, as students progressed through the grades, they demonstrated considerable literacy practices in Knowledge Building through their reading, writing, and revision activities in KF. Knowledge Building also enabled students to engage with vocabulary in sophisticated ways, representing different types of literacy practice. Connections between vocabulary knowledge and scientific understanding could be observed, which point to the notion of vocabulary knowledge—knowledge about word meanings—being a subset of general knowledge (Nagy & Herman, 1987, p. 28) and the richness of the Knowledge Building approach towards literacy development.

Conclusions and implications

This study explored the development of productive vocabulary in a group of Knowledge Building students across the elementary school years. Results of lexical analysis indicated that students tended to produce more tokens, more unique word types, and text with an increasingly higher proportion of infrequent words with every year. In the absence of a control group, one may argue that this phenomenon simply reflects the natural cognitive development of school children. However, correlation analyses between lexical measures and Knowledge Building behavioural indicators identified significant correlations between students' productive vocabulary size and reading, writing, and revisions on Knowledge Forum. Moreover, note revisions emerged to be the strongest predictor of the rate of vocabulary growth in each year. Further content analysis uncovered interesting moments when vocabulary learning happened naturally through Knowledge Building discourse. Overall, the present study highlights the potential benefits of Knowledge Building for vocabulary growth. Our findings support the socio-pragmatic and sociocultural notion that the acquisition of new vocabulary is more meaningful in authentic social contexts, in our case, the KB classroom. When cognitive responsibility is handed over to students, not only do they willingly help one another in grappling with new vocabulary, they also do so successfully. Instead of waiting for the teacher to provide them with a new vocabulary list, students sought out new words to learn as they worked toward improving their community knowledge; students collectively owned their vocabulary. In other words, vocabulary learning is an authentic and integrated practice of KB. Sustained work with ideas and knowledge advancement led to the progressive growth of the students' collective lexicon.

Of special interest to the authors is the potential of applying lexical indicators in the development of future Knowledge Building analytics, so that individual and collective conceptual development could be detected. Previous work has highlighted this link between literacy skill and knowledge advancement in Knowledge Building (Zhang & Sun, 2011). Future work should seek to model knowledge advancement in the current dataset, as well as devise new analytic tools dedicated to literacy learning in Knowledge Building.

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Learning Resilience in the Face of Bias: Online Gaming, Protective Communities and Interest-Driven Digital Learning

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Abstract: Online digital gaming environments have been proposed as an important form of computer-supported collaborative learning, but these environments have been shown to marginalize some learners, most notably women or girls, as well as ethnic or racial minorities. Furthermore, game-based competencies and identities have been shown to be important for digitally-mediated learning activities and trajectories in computer science and technology. In this paper we look at how supportive communities can improve resilience by mitigating stereotype threat, and thereby helping to protect vulnerable groups from the negative effects of implicit and explicit bias in gaming culture and game-based learning activities. Our findings demonstrate that a female-supportive gaming community can foster equitable gaming identification and self-concept, and we propose that similar models can be used with other marginalized groups (i.e., ethnic/racial minorities).

Keywords: online gaming, digital games, gender, race, ethnicity, stereotype threat, social identity theory, communities of practice, informal learning, interest-driven learning, 21st century learning

Introduction

Gaming has often been cited as inequitable in its social practices, particularly for females. In an era where informal learning spaces and communities are increasingly contributing to meaningful skill development, domain identification and learning trajectories, understanding the ways these spaces can be inclusive to certain learners and marginalizing to others becomes increasingly important in meeting equity goals. This paper builds off of previous work that explores the interrelationship between social experiences in online gaming and its effects on the investment, self-perceptions of domain competency (i.e., gaming ability), and the social practices of gamers, across gender (Richard, 2013a; Richard & Hoadley, 2013). Specifically, we focus on the role that online gaming communities play as a form of computer-supportive collaborative learning.

We begin by focusing on the mitigating and mediating negative social practices in online spaces, and how supportive communities can be protective for vulnerable players (namely, female and ethnic minority players). We first examine how gaming activities can support learning, as well as marginalize certain sociocultural identities. We then explore the relationship amongst community perceived support, gaming identification and gaming self-concept to see how identity supportive participation structures can play a role in fostering resiliency against stereotype threat for marginalized groups (i.e., whether female-supportive communities can level the playing field for women). Finally, we discuss the findings in light of creating inclusive and equitable spaces for computer supported collaborative learning.

Gaming communities as spaces of learning and practice

Literature continues to demonstrate that digital, mediated and online spaces offer opportunities for learning and developing interest-driven competencies, and emerging and necessary 21st century literacies (e.g., Gee, 2004; Halverson, 2012; Hayes & Duncan, 2012; Ito, et. al, 2010; Jenkins, Clinton, Purushotma, Robinson & Weigel, 2006; Kafai, Peppler & Chapman, 2009; Squire, 2011; Thomas & Brown, 2011). Much has been written about how "affinity" spaces can not only be models for education through interest-driven learning within authentic contexts, but can also serve as learning environments themselves where applied and authentic expertise forms through learning with others (e.g., Gee, 2004; Hayes & Duncan, 2012). Increasingly, online multiplayer game environments are being used as exemplary models of authentic learning communities from which motivation can be fostered (e.g., Dickey, 2007), and collaborative and constructivist learning has been documented (e.g., Squire, 2011; Steinkuehler, 2004; Steinkuehler & Duncan, 2008; Voulgari & Komis, 2010).

Capitalizing on gaming communities as learning spaces raises questions about who can benefit from such spaces. Access across gender, in particular, is an area of concern that has been raised over the past 30 years (e.g., Bryce & Rutter, 2003; Kiesler, Sproull & Eccles, 1985; Yee, 2008). Researchers have, on the one hand, looked to the motivation games produce as a potential technique to engage learners. But, on the other hand, researchers have also noted the wide disparity of who is present in these game-based affinity spaces as they currently exist. In the next section, we explore the issue of gender and access to gaming.

Games, gender and marginalization

Early work that sought to understand why women or girls were not playing and participating as much or in the same way as men or boys thought game themes were male-oriented, and felt that females wanted less difficult games or more whimsical themes (e.g., Morlock, Yando & Nigolean, 1985; Wilder, Mackie & Cooper, 1985). Related work proposed that females and males have different learning styles and prefer certain design elements, a popular concept shared by many game designers (e.g., Braithwaite & Shreiber, 2009; Ray, 2004; Schell, 2009). Later work examined more culturally constructed models of gender in the context of gaming (e.g., girls have been taught to like certain games) citing the influence of culture, access and experience (e.g., Carr, 2005; Dickey, 2006; Taylor, 2008).

If gaming is to be used as a context for promoting learning (whether technology-oriented learning or more self-directed learning as with affinity spaces), we certainly should consider both the differences of learners across different sociocultural experiences, along with overarching cultural assumptions. But, these issues may not be the most important factor in determining who has equitable access to these learning spaces. As asserted by Lave and Wenger (1991), learning in communities of practice is contingent on power relations. Similarly, related research (e.g., Goode, 2010; Margolis & Fisher, 2002) has documented the role that differential gendered expectations and support around computing – including playful experimentation fostered through gaming (Cassell & Jenkins, 1998; Kiesler, Sproull & Eccles, 1985) - from early ages and beyond contribute to the gender gap in computing and technology. This bears the question of whether women and girls are able to develop identities of learning within the power dynamics of gaming culture.

A long line of research on gender and games demonstrates that females often don't have the same efficacy as males when it comes to digital games and game culture. However, newer research is finding that gender differences in abilities and perceived abilities were often diminished once females had the opportunity to train and engage in gaming (e.g., Feng, Spence & Pratt, 2007; Jensen & deCastell, 2011). Furthermore, research highlights that the ways games and game marketing portray the social context around gender and ethnicity can have measurable, negative effects on players' sense of who belongs in gaming and virtual environments, which often precludes women and girls (e.g., Behm-Morawitz & Mastro, 2009) and racial or ethnic minorities (Dill & Burgess, 2012). Similarly, lack of diversity and representation can have similar effects on efficacy for marginalized gamers (e.g., Lee & Park, 2011). Research also demonstrates that females and racial/ethnic minorities are likely to have lowered domain self-concept when presented negative stereotypes or marginalized representations of their respective groups, which is often the case (e.g., Behm-Morawitz & Mastro, 2009; Williams, Martins, Consalvo & Ivory, 2009). For example, Williams, et. al. (2009) found that male characters and White characters, respectively, each made up over 85% of primary characters, and many game types did not have any representational diversity.

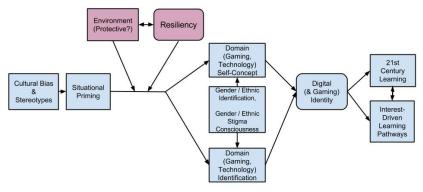
Furthermore, most play spaces, in the home or in public gaming environments (e.g., the arcade or gaming conventions), are often structured around gender dynamics, such that males were given more agency to demonstrate their abilities and authority (e.g., Bryce & Rutter, 2003; Kiesler, Sproull & Eccles, 1985). Online spaces are similarly mediated by male experience (Yee, 2008), which forces some females to hide their gender when playing online. However, this is increasingly difficult with the rise of voice-based gaming communication (Richard, 2013b; Gray, 2012) and profile stalking, the act of looking up ones' online identity (Richard, 2014). Recent work has found that females as well as ethnic/racial minorities are often victims of harassment (Gray, 2012; Richard, 2013c; Richard, 2014) and females are three times more likely to experience harassment when using voice-based chat online regardless of skill (Kuznekoff & Rose, 2013). All of these factors show support that online gaming may negatively affect the amount of investment and self-concept female and ethnic minority players have with gaming, as well as their ability to engage equitably in online social play.

Mechanisms of marginalization

Both stereotype threat (Steele & Aronson, 1995; Steele, 1997) and social identity theory (Tajfel & Turner, 1986; Eccles, 2005) address how identities form in relation to sociocultural experiences, which can support or inhibit identification with certain fields, domains and aspirations. Stereotype threat, in the short term, can cause stress for individuals stereotyped to underachieve in a domain, which limits their working memory and inhibits their performance when triggered. It can be triggered overtly (e.g., through harassment) or ambiguously (e.g., maleoriented themes or advertising). Over time, stereotype threat and unsupportive learning climates can lead to domain disidentification (Steele, 1997; Picho & Stephens, 2012). For example, groups frequently stereotyped with underperformance in math or science will eventually disidentify with that area, and choose not to engage in relevant learning and performance activities (Hill, Corbett & St. Rose, 2010; Steele, 1997; Spencer & Aronson, 2002). In studies where stereotype threat was measured in computer and technology environments, researchers found that females were more likely to attribute failure to their own technical inabilities than males in general

and females not in a stereotype threatening situation (Koch, Muller & Sieverding, 2008). Researchers have found that marginalized gamers are more likely to not identify with gaming, and efforts for targeted representation don't rectify this issue (Shaw, 2012). For most marginalized gamers, the exclusivity of game culture seems to be a greater barrier (Richard, 2013b; Shaw, 2012).

In other words, when we see studies that highlight female distaste and eventual disidentification with computer and technology careers and interest-driven trajectories (e.g., Anderson, Lankshear, Timms & Courtney, 2008), we may be witnessing the byproduct of both culturally constructed dissonance and stereotype threat disidentification. Essentially, these kinds of studies highlight the interrelationship between context and identification with competencies and associated careers. In short, it may be that there is gender inequity in online games due first to sociocultural practices (i.e., male-oriented design, and differential female support to play), and then the harassment and marginalization that results due to the incongruence between social identities and expectations in the play space, which can both invoke stereotype threat. This, then, causes females to disidentify and either leave the domain or to face difficult compromises such as self-misrepresentation (pretending to be male), disidentification with their marginalized stereotype threat vulnerability is indeed higher for females and ethnic/racial minorities in digital gaming.



<u>Figure 1.</u> Logic Model of how environmental factors affect identification, self-concept and interest-driven learning trajectories, as well as the role of protective environments and resiliency in mitigating those outcomes.

Supportive spaces and fostering resiliency

Not all individuals will be subjected to or similarly vulnerable to stressors (like stereotype threat) or positive influences. However, researchers caution that, even though most individuals exhibit strong resiliency against all odds, positive role models and environments are especially important in mitigating negative stressors and resulting negative outcomes for vulnerable groups (Benard, 2004). Protective environments have been found to have "particular importance when adversity levels are high" (Werner, 2013, p.99). Positive educational climates and teachers have been found especially helpful because they serve as sources of support and role models for learners, sometimes in place of other caring structures or individuals (Benard, 1993).

Protective processes have been seen to "counteract the harmful effect of stressors (such as educators providing normative coping strategies for students during school transitions...)" and protective enhancing processes strengthen an individual's capacity to manage stressors on their own (Reyes, Elias, Parker & Rosenblatt, 2013, p. 351). Since protective environments and interventions can only extend so far, aiding individuals in developing their own coping strategies has been seen as especially useful for long-term outcomes beyond the supportive structure or intervention (Werner, 2013).

To summarize, interest-driven and informal learning operates within sociocultural context, which can shape the kinds of learning trajectories individuals will eventually invest and partake in, as outlined in figure 1. One successful approach to leveling the playing and learning field is to train people to be resilient and provide both safe havens and skills that allow individuals to resist the negative effects of stressors.

Supportive community as a model of interest-driven learning and resiliency

In this study, we further explore a longstanding explicitly female-supportive (yet co-ed) gaming community, named PMS Clan. Our work (Richard, 2014; Richard, 2013a; Richard & Hoadley, 2013) underscored the level of investment required by this community. While skill is not a requirement to join, many members train with highly skilled players who compete in tournaments, and can go on to compete in tournaments, or just play with

the community in low-stakes online matches during practices. Telling of its success with this model, female members of this community are some of the most visible females in the professional gaming circuit. As further discussed in Richard (2014), community structures reinforced learning as central to the community, through its highly regulated practices and emphasis on bettering skills and mastery. Members must practice and play with the community at least four hours a week.

However, participating in the community is also a tale of resiliency. As a central component of the community's mission, and a regular part of practice activities when playing in the community together online against random opponents, members are taught to cope with the kinds of regular and negative behavior they are subjected to. As part of membership, individuals not only are required to be respectful and supportive of marginalized groups (females, ethnic minorities and LGBTQI players) but are also taught to be good sports in the face of adversity, and use their fellow members as sources of venting and support after matches (see, Richard, 2014). In this sense, the community serves a protective process and protective-enhancing process.

Method

In past studies, we found (Richard & Hoadley, 2013) that members of this female-supportive community exhibited higher gaming identification and self-concept than members of other communities. Female and male members in the female-supportive community were equal in their gaming identification (in other communities, gaming identification was significantly higher for males than females). Here, we seek to further understand the relationship between communities, and their structures on members' identification and sense of ability. Specifically, what is the role of member perceived support, and community structures, and which is the best predictor? The research questions explore herein are: What is the relationship between community perceived support, gaming self-concept and gaming identification? If the possible effect of community is controlled for, can community perceived support predict gaming self-concept and gaming identification?

Measures

The survey was one part of a larger, mixed-methods study (with surveys, interviews and ethnographic participant observation) on gaming experience, online communities, and learning-relevant outcomes conducted primarily between 2009-2012 (Richard, 2013a). The two measures reported here were derived from the Perceived community support questionnaire (PCSQ) (Herrero & Gracia, 2007) and the Social Identities and Attitudes Scale (SIAS) (Picho & Brown, 2011). The PCSQ is made up of three scales, which assess three aspects of community support. Community integration measures sense of belongingness and identification to a community, community participation measures how much one is involved in social activities in the community, and community organization measures the degree of support a respondent perceives. Items were measured on a 5-point Likert scale from (1) strongly disagree to (5) strongly agree. Only two measures from the SIAS are analyzed in this study: domain (gaming) identification and self-concept. Both of these measures were used in past studies to assess the role of communities in shaping identification and self-concept, across gender. The PCSQ was revised slightly to reflect gaming communities instead of general community organizations, and to account for some wording that didn't make sense in translation from Spanish. The original scale demonstrated good internal consistency for the overall scale ($\alpha > .85$) and its subscales ($\alpha > .75$). Reliability analysis was run for the revised PCSO, which demonstrated high internal consistency for the overall scale ($\alpha = .92$) and its subscales for community integration ($\alpha = .76$), community participation ($\alpha = .86$) and community organization $(\alpha = .84).$

Participants and context

Participants were self-identified game players, 18 or older (due to human subjects constraints), who responded to calls for participation, widely disseminated across several gaming communities, including the female-supportive one, and some social networks associated with the researchers' institution, located in the Northeastern United States.

Data analysis

The Pearson product-moment correlation coefficient was used to evaluate the relationship between perceived community support, gaming self-concept and gaming identification for female-supportive community (FSC) as compared to other communities, since the FSC demonstrated higher levels of gaming self-concept and identification in general over other communities in previous analyses (Richard & Hoadley, 2013). Preliminary analysis were performed to ensure that there weren't violations of the underlying assumptions of normality, linearity and homoscedasticity. Results demonstrate that for individuals in communities other than female-

supportive one, the PCSQ has a significant positive relationship with gaming identification (r = .33, n = 39, p = .04); the subscale community participation has a significant positive relationship with gaming identification (r = .33, n = 39, p = .04) and gaming self-concept (r = .34, n = 39, p = .04); and the subscale community organization has a significant positive relationship with gaming identification (r = .36, n = 39, p = .02). There were no significant relationships between the PCSQ or its subscales in the FSC. Table 1 contains the Pearson product-moment correlations, divided by community membership, across gaming identification, gaming self-concept, the PCSQ and its subscales.

	Female Supportive (FSC)				Other communities							
Measure	1	2	3	4	5	6	1	2	3	4	5	6
Gaming Identification	-	.42***	0.22	0.13	0.23	0.18	-	.76 ***	.33*	0.17	.32*	.36*
Gaming Self-Concept		-	0.002	-0.04	0.05	-0.04		-	.32*	0.26	.34*	0.17
PCSQ			-	.88***	.89***	.81***			-	.83***	.93***	.88***
Community Integration				-	.63***	.75***				-	.62***	.70***
Community Participation					-	.51***					-	.71***
Community Organization						-						-

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Table 1: Correlations, divided by community membership

* p < .05, ** p < .01, *** p < .001 (2-tailed)

The correlations demonstrated that perceived community support, as measured with the PCSQ, has a significant positive relationship with gaming identification, particularly for members of communities other than the female supportive one. Further, the subscale community participation and gaming self-concept had a significant positive relationship for members of communities other than the FSC. However, there appeared to be no significant relationship between perceived community support and gaming identification or self-concept for members of the female-supportive community. As a result, we found it important to investigate whether community perceived support predicted gaming identification or self-concept over and above community membership.

A hierarchical linear regression was first run on gaming identification (table 2), which previously demonstrated the strongest positive relationship with the PCSQ and its subscales, with community membership (FSC or other community) put in the model first, followed by the subscales of the PCSQ. Using Cohen's (1998) criteria, the table of correlations show that gaming identification has a medium positive correlation with the female-supportive community membership (r = .42, n = 103, p < .0001). The table of correlations further showed that community participation and community organization had small positive correlations with gaming identification, r = .26, n = 103, p < .01, and r = .27, n = 103, p < .01, respectively. There wasn't a significant correlation between community integration and gaming identification, r = .04, n = 103, p < .35.

Community membership was entered in step 1 and explained 17.7% of the variance in gaming identification, F(1, 101) = 21.68, p < .0001. After entering the subscales of the PCSQ into the model in step 2, the total variance explained by the model increased to 26.6%, F(3, 98) = 8.86, p < .0001. Examining the change in the model, it is evident that the addition of the PCSQ subscales explained an additional 8.9% of the variance, R square change = .89, F change (3, 98) = 3.95, p= .01 (see table 2). However, in the final model, only community membership was statistically significant (*beta* = .36, p < .0001), though community participation (*beta* = .22, p= .057), and community organization (*beta* = .24, p = .07) were reaching significantly contribute to gaming identification after controlling for the influence of community. In other words, community membership contributes more significantly to gaming identification than perceived community support within the community does.

A hierarchical linear regression was then run using the same process on gaming self-concept (see table 2), by first entering community membership in step 1 followed by the subscales of perceived community support. The table of correlations show, once again, that gaming self-concept has a small positive correlation with female-supportive community membership (r = .27, n = 103, p < .01). It also further shows that community participation has a small yet positive correlation with gaming self-concept (r = .17, n = 103, p = .04). FSC membership was first entered into the model in step 1 and explained 7.4% of the variance in gaming self-concept, F(1, 101) = 8.01, p < .01. After entering the subscales of the PCSQ into the model in step 2, the variance explained increased to 10.2%. However, while the model as a whole is significant, F(3, 98) = 2.8, p = .03, the change in R square is not, indicating that the subscales of the PCSQ do not explain the additional

variance in gaming self-concept, *R* square change = .03, *F* change (3, 98) = 1.03, p = .38. In other words, the subscales of the PCSQ do not add significantly to gaming self-concept, after controlling for gaming community membership. Gaming community membership remains the stronger predictor of gaming self-concept, though the entire model only explains a small amount of the variance.

	b	SE B	β	р		b	SE B	β	р
Step 1					Step 1				
Constant	4.94	0.13 9		<i>p</i> <.001	Constant	5.46	0.12		<i>p</i> <.001
	(4.67, 5.22)					(5.21, 5.70)			
Community	0.82				Community	0.44			
Membership (FSC or other)	(.47, 1.17)	0.18	0.42	<i>p</i> <.001	Membership (FSC or other)	(.134, .754)	0.16	0.27	<i>p</i> <. 01
Step 2					Step 2				
Constant	3.53	0.55		<i>p</i> <.001	Constant	4.86	0.50 5		<i>p</i> <.001
	(2.45, 4.62)					(3.86, 5.87)			
Community	0.7				Community	0.43		0.26	
Membership (FSC or other)	(.33, 1.06)	0.18	0.36	<i>p</i> <.001	Membership (FSC or other)	(.093, .766)	0.17	4	<i>p</i> = .01
Community	-0.24	0.18	-	<i>p</i> = .18	Community	-0.024	0.17	-0.02	p = .89
Integration	(61, .117)	0.10	0.19	p = .10	Integration	(358, .310)	0.17	-0.02	<i>p</i> = .87
Community	0.29	0.15	0.22	p = .057	Community	0.213	0.14	0.19	<i>p</i> = .13
Participation	(01, .59)	0.15	0.22	p = .037	Participation	(064, .491)	0.14	4	<i>p</i> – .13
Community	0.32	0.18	0.24	p = .069	Community	-0.03	0.16	-0.03	p = .86
Organization Note $P^2 = 177$ for	(026, .67)			·	Organization Note $P^2 = 0.74$ f	(352, .292)			1

Table 2: Left: Linear m	odel of predictors of	gaming identification.	with 95% confidence inte	ervals in parenthesis.
Right: Linear model of predictors of gaming self-concept, with 95% confidence intervals in parenthesis.				

Note. $R^2 = .177$ for Step 1; $\Delta R^2 = .089$ for Step 2 (p = .01) Note. $R^2 = .074$ for Step 1; $\Delta R^2 = .028$ for Step 2 (p = .38)

Discussion

The statistical results indicate that the holistic measure of perceived community support has a significant positive relationship with gaming identification and the subscale of community participation had a significant positive relationship with gaming self-concept, if, and only if, one were in communities other than the female supportive community. There was not a significant relationship between perceived community support or any of its separate sub-scales with gaming identification or self-concept for individuals in the female supportive community. However, membership in the female supportive community positively predicts higher gaming identification and self-concept than does perceived community support. In other words, while members of the female supportive community may not perceive it as supportive, membership in the community contributes over and above general support. One interpretation for these results is that the community provides structures other than perceived support that help with fostering resiliency and increasing identification and efficacy. One possibility is the presence of role-models that defy stereotypes of female inability in gaming spaces (since the community contains multiple highly ranked and professional female gamers); another possibility is that its tactics for providing a structured way to deal with harassment online while playing with the community, which involves reporting and muting negative players, while maintaining sportsmanship (Author, 2014), could be scaffolding and modeling a healthier way to deal with threat. As a result, players could have positive structures to help build investment, confidence, identity and ability.

Conclusion, limitations and future directions

The emergence of learning through affinity spaces holds much promise. The voluntary nature and authenticity of such spaces has led many to observe profound learning taking place that would be challenging to provide in formal learning contexts, and the degree of personal identification and identity development with affinity spaces like gaming cultures may lead to this learning being more impactful for the participants than learning which was driven by others' interests. However, the dark side of affinity spaces is that they may be marginalizing to certain groups. While prior research has focused on the way that designed elements of such spaces may marginalize or

fail to attract women and girls (and may also have tried to identify ways to design segregated spaces for women and girls), these approaches treat marginalization as a byproduct of the differences in the marginalized groups. In short, they treat inequity as a woman's problem, rather than a culture problem. Still, cultures can be changed, in part through leadership and the presence of diverse role models. Minority role models have to come from somewhere; often the most resilient among marginalized groups are the ones who can succeed. This work demonstrates that one important technique for changing cultures that perpetuate inequity is to create learning sub-communities that help protect the marginalized and train for resilience. While this paper has focused on the role this distinct female-supportive community has played in supporting the resilience of female players, we also have anecdotal evidence that the same community provides support for other marginalized groups, including ethnic, racial, and sexual minorities (see, Richard, 2013a). This suggests that resilience-oriented communities can be protective of many groups, and that such protective communities may in fact be able to contribute to culture change more generally towards tolerance and/or achievement in the face of adversity.

In CSCL and the learning sciences, the need for facilitation and the importance of cultural assumptions in equitable participation in collaborative learning have been well documented for many years (for example, Hsi & Hoadley, 1997; Hoadley, 2002; Lee & Hoadley, 2006). However, responses to these needs has been primarily to focus on improving the designed environment and/or overlaying tools. This work shows that treating resilience as an important learning outcome, and the intentional creation of protective communities, is another viable technique. While this study only looked at female-supportive communities, it offers implications for identity-supportive communities across sociocultural experiences. Richard (2013a) has found that ethnic/racial minorities, in particular, are similarly vulnerable to stereotype threat in gaming. A future direction of this work would be to explore its efficacy for members of other marginalized groups, such as ethnic/racial and sexual minorities. Moreover, further research is needed on how such communities accomplish their protective role, how this role may or may not extend beyond the practice fields in which the communities function, and how to dissect what aspects of equity, or inequity, may be attributed to designed environments vs. the cultures that spring up in those environments.

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Fostering Discussion across Communication Media in Massive Open Online Courses

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Abstract: This paper presents data from one cycle of a design based research process in which we grapple with challenges in engaging students in more intensive discussion based interactions in Massive Open Online Courses (MOOCs). We compare across three communication media provided to students in that context in terms of relative popularity and overlap in student sub-populations. We also compare the communication between these contexts in terms of their content focus, concentration of reasoning articulation, and the interaction between the two. This comparison allows investigating the specific contribution of synchronous collaboration in a MOOC, which is relatively novel. The analysis suggests that there is value in providing a diverse set of discussion contexts in that they may lend themselves to differently natured interactions, but that it creates a need for greater efforts towards effective bridging between media and channeling of students to pockets of interaction that are potentially of personal benefit.

Keywords: discussion affordances, massive open online courses, reasoning

Introduction

As the field of online education increases its focus on delivery of effective instruction at massive scale as in Massive Open Online Courses (MOOCs), we become more painfully aware of teaching resources as a limited commodity. Analyses of attrition and learning in MOOCs both point to the importance of social engagement for motivational support and overcoming difficulties with material and course procedures (Breslow et al., 2013). Furthermore, we learn from the field of Computer Supported Collaborative Learning (CSCL) that with proper support, students can learn substantially from their interactions with other students (Fischer et al., 2013). However, the reality of current content-focused xMOOCs, such as the typical MOOCs offered through Coursera, edX, and Udacity, is that opportunities for exchange of ideas, help and support are limited to threaded discussion forums, which are often not well integrated with instructional activities and as a result lack many of the qualities identified as reflecting instructionally beneficial interactions from prior work in the field of CSCL (Rosé et al., 2014). In contrast, constructivist MOOCs, or cMOOCs, typically provide an eclectic variety of affordances for social interaction including blogs, Twitter communication, email, Facebook study groups and others, with the idea that students should have the freedom to find a context for learning socially within this variety that they feel comfortable with, which may be effective for engendering a wider variety of discourses contextualized within the learning and therefore meeting different instructional needs (Siemens, 2005; Smith & Eng, 2013). One downside of this approach, however, is that many students find the variety disorienting and anxiety-inducing, especially those who lack appropriate self-regulated learning skills.

This paper presents data from one cycle of a design based research process in which we grapple with these trade-offs as we seek effective practices for incorporating theory-motivated discussion based learning opportunities in MOOCs. Specifically, we aim to import from the field of CSCL insights into the specific affordances for instructionally beneficial conversational interaction offered by alternative online discussion contexts as well as insights into what might be productive strategies for moving among them so that appropriate, integrated support and guidance for students could be designed and offered. In the first cycle within this iterative process, which we report on in this paper, we have developed two interventions to address specific limitations we have seen in the current generation of xMOOCs, and then deployed them in a recent edX MOOC. In the remainder of the paper we describe the prior work that motivated the design of these interventions. We then present our deployment effort and the interpretation of the data that has been collected during the first two weeks of this edX MOOC that provides the context for our study. Finally, we conclude with plans for next steps in the iterative design based research process.

Foundational work

The central means of communication provided by many courses is still the traditional web forum. Nevertheless, Web 2.0 technologies provide diverse opportunities for discussion in MOOCs, some of which have been utilized in that context. However, so far there is no coherent vision for seamless, effective integration of these technologies with MOOC based instruction. Instead, social communication in MOOCs, as in the web in general, is both eclectic and highly fragmented. For example, it is almost a given that for typical MOOCs, several groups in social networks such as Facebook or Google+ are created and sometimes actively maintained by the student population, but much more frequently quickly abandoned. Twitter is another social media outlet that is sometimes used in MOOCs, more often in cMOOCs than xMOOCs, which is mainly used as a broadcast medium but also exhibits instances of short public discussions. Discussion may also take place in connection with blog posts. This eclectic organization leaves students not having a clear picture of where to go to engage in discussion that interests them (Smith & Eng, 2013).

Most agree that social interaction in general and discussion in particular is not a major portion of the experience the majority of MOOC students have. Nevertheless, the inner workings of student experience in that context has been investigated in early work on MOOCs. Recent work studying social interaction in MOOCs has focused on identifying factors associated with attrition rather than learning (Wen et al., 2014a; Wen et al., 2014b; Yang et al., 2014). The motivation for this work is that scarce human resources could be channeled to where they are most needed, or augmented with automated forms of just-in-time support, that might enable students to persist in the course through times of elevated vulnerability. These hypotheses about what factors would ultimately flag students at risk have been validated by utilizing a statistical analysis technique referred to as survival analysis, which has been used to gauge the impact of time variant factors on dropout in other types of online communities (Wang, Kraut, & Levine, 2012). Factors that have been successfully modeled through discourse analytics, and which have been validated as significant predictors of dropout using survival modeling, include motivation and cognitive engagement (Wen et al., 2014a), student attitudes towards course affordances and tools (Wen et al., 2014b), satisfaction with help received, and relationship formation and loss (Yang et al., 2014). Of all of the factors explored so far, the most dramatic impact on attrition was related to relationship formation and relationship loss in the MOOC discussion forums, even though the students who participate in those forums are among the most highly committed to the course to begin with.

In these results we find support for the importance of community, and evidence of the potential positive impact of work towards integration in the community, and engagement in joint meaning making towards deeper engagement with the course materials. If students drop out of a course early, no matter how valuable the instructional materials are, students will not have the opportunity to benefit from them. Beyond issues of attrition, the literature on discourse analytics in the context of MOOCs also views conversational interactions from the standpoint of what is valuable for learning. Across many different frameworks for characterizing discourse patterns associated with successful collaborative learning, the idea of eliciting articulation of reasoning and idea co-construction is a frequent central element (Chan, 2013; Chin & Clark, 2013; van Alst, 2009). Thus, in our work it is a specific goal to provide affordances for engaging in this behavior through scaffolded synchronous collaboration, which is novel in a MOOC context. In contrast to other studies comparing features of communication across media (Meyrowitz, 1998; Watson-Manheim & Balanger, 2007), the goal of our specific investigation is to understand how MOOC students in a platform that includes choices in where to engage in discussion, choose to engage differently in learning relevant practices such as articulation of reasoning and help exchange across communication media.

MOOC design

Building on the understanding gained through analysis of conversational interactions in a wide variety of instructional settings, interventions have been developed and successfully deployed in both classroom and online settings that support effective collaboration and learning in those settings. In this section we describe two interventions designed to provide opportunities for discussion based learning. While one of the interventions focuses on help exchange, the other focuses on collaborative reflection. Both interventions were deployed in a nine week long MOOC on Data, Analytics and Learning (DALMOOC) that was offered on the edX platform between October and December 2014 with a total of 20,991 registered students. Our analyses are focused on the first two weeks of the course since that was the time of most intensive usage of the conversational interventions.

The Quick Helper

The first intervention, called the Quick Helper, is designed to support help seeking as well as increase the probability that help requests will be met with a satisfactory response. While virtually all MOOCs offer threaded discussion affordances where students can post help requests, some students are reticent to ask for help, and

even when students do post help requests, many of these requests go unanswered. Our help seeking intervention connects students, whose questions may go unresolved, with student peers who may be able to answer their questions. The Quick Helper is continuously available to students by means of a button. When they click, they are guided to formulate a help request. The help request is posted to the DALMOOC discussion board, and the text and metadata are forwarded to our Quick Helper system. Using this help request, a social recommendation algorithm selects three potential help providers from the pool of student peers. The student is then given the option to invite one or more of these potential helpers to their thread as shown in Figure 1. Once selected, an email with a link to the help request thread is then automatically sent to the selected helpers inviting them to participate in the thread. In the first two weeks of DALMOOC, 77 unique students elected to use our Quick Helper system approximately 127 times. Further discussion of our initial interventions applied to Quick Helper and its results are out of the scope of this paper.

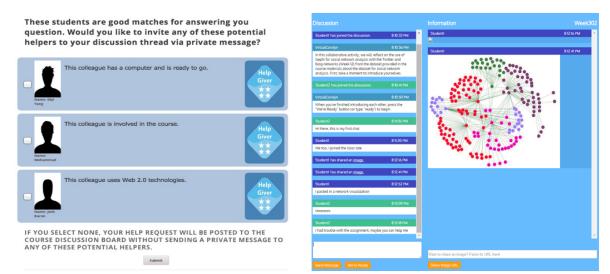


Figure 1. A screenshot of the helper selection in Quick Helper (left) and the Bazaar Collaborative Reflection chat (right).

Bazaar Collaborative Reflection

A second intervention, referred to as Bazaar Collaborative Reflection, makes synchronous collaboration opportunities available to students in a MOOC context. Research in Computer-Supported Collaborative Learning has demonstrated that conversational computer agents can serve as effective automated facilitators of synchronous collaborative learning (Dyke et al., 2013). However, typical MOOC providers do not offer students opportunities for synchronous collaboration, and therefore have not so far benefitted from this technology. Students click on our Lobby program and are matched with one other student that is also logged in to it. Once matched, they are provided with a link to a chat room where they can work with their partner students on a synchronous collaboration activity, supported by a conversational computer agent. This work builds on earlier findings from a series of studies where a Computer Facilitator has improved learning during collaboration (Dyke et al., 2013; Adamson et al., 2014).

In order to gain a deeper understanding of the problems that may arise from synchronous collaborative activities in MOOCs, we integrated a collaborative chat environment with interactive agent support. In order to facilitate the formation of ad-hoc study groups for the chat activity, we make use of a simple setup referred to as a Lobby. Students enter the Lobby with a simple, clearly labeled button integrated with the edX platform. In order to increase the likelihood of a critical mass of students being assigned to pairs, we suggested a couple of two hour time slots during each week of DALMOOC when students might engage in the collaborative activities. These timeslots were advertised in weekly email newsletters. However, the chat button was live at all times so that students were free to attempt the activity at their convenience.

Upon entering the lobby, students are asked to enter the name that will be displayed in the chat. When successfully matched with another learner, the student and their partner are then presented with a link to a chat room created for them. If another student does not enter the Lobby within a couple minutes, they are requested to return later. A visualization is presented to the student that illustrates the frequency of student clicks on the button at different times of the day on the various days of the week so that they are able to determine the best time to return. Students enter the synchronous chat room via the link, and interact with each other as well as a conversational agent who appears as a regular user in the chat, as shown in Figure 1. This chat setup has been

used in earlier classroom research (Adamson et al., 2014). In our initial investigation in DALMOOC, we make use of statically scripted agents who guide the students through course-related discussion questions but future investigations may include agents that dynamically react to the students as in our earlier work (Dyke et al., 2013; Adamson et al., 2014).

Method

The goal of our analysis is to compare across three communication media affordances for help exchange and collaborative reflection. Since the first week of the course may be anomalous due to students getting oriented to the organization and material, we sampled from two different weeks. We avoided sampling from the same students in the two weeks as much as possible in order to minimize any statistical dependencies between weeks.

Data

Table 1: Descriptive statistics over sampled communication data for analysis

	Unique Students	Units	Messages	Words
Bazaar (week1)	42	38	242	6,069
Bazaar (week2)	42	37	377	3,124
Forums (week1)	124	200	200	8,108
Forums (week2)	101	200	200	13,401
Twitter (week1)	77	100	100	1,663
Twitter (week2)	73	100	100	1,740

For our analysis we sampled from communication data in three streams, namely, the Bazaar chats, the Forum posts, and the Twitter tweets. It was our goal to sample in a way that would give us broad exposure across students and weeks in an unbiased way. From the discussion forums, we randomly sampled 200 posts per week after filtering out any messages posted by instructors or staff. Tweets have been collected using the TAGS Twitter Archiver, which was configured to retrieve all tweets containing the #dalmooc hashtag that identifies tweets pertaining to the course. In interest of broad sampling, for each user, we kept at most two tweets and removed all tweets by instructors or staff. We also removed duplicates and retweets. From the resulting set of tweets, we selected 100 contributions per week. For the chat data, in order to identify a unit with approximately as much content as the discussion posts, we chose as a unit of analysis a chunk of conversation occurring between two agent prompts, where each of these agent prompts was designed to start a new topic of conversation. Within each chunk, we considered all of the contributions belonging to the same speaker as a single unit, although we interpreted it within context. In interest of broad sampling, we chose to sample one chunk per chat transcript and disregarded all chats with less than two students (e.g. conversations between a single student and the agent). However, in some chunks, only one speaker spoke, which explains why the number of units is sometimes less than 42. Due to the lower number of chats in the second week of the course, we sampled 21 chunks per week in order to have an even distribution across weeks.

Data coding

	Social	Course Process	Course Content	Reasoning
Bazaar (week1)	18 (47.4%)	23 (60.5%)	14 (36.8%)	26 (68.4%)
Bazaar (week2)	22 (57.9%)	7 (18.9%)	21 (56.8%)	22 (59.5%)
Forums (week1)	39 (19.5%)	88 (44.0%)	53 (26.5%)	62 (31.0%)
Forums (week2)	32 (16.0%)	88 (44.0%)	80 (40.0%)	67 (33.5%)
Twitter (week1)	19 (19.0%)	31 (31.0%)	38 (38.0%)	28 (28.0%)
Twitter (week2)	7 (7.0%)	38 (38.0%)	57 (57.0%)	35 (35.0%)

Table 2: Descriptive statistics over coded data

In order to get a sense for the differences in the discourse occurring within our three communication contexts, we coded each contribution along two dimensions. The first dimension used three thematic distinctions to enable us to identify talk segments pertaining to three primary purposes, which were not treated as mutually exclusive: Social, Course Process, and Course Content. Social segments were ones where students worked to

create social connections with one another by sharing personal information, including contact information for further interaction. Course Procedure segments were ones in which the structure of the course, the course environment, or course procedures were discussed. And finally, Course content segments were ones in which the conceptual content of the course was substantively discussed. In order to locate discussion that potentially contributes to content learning, the primary relevant discussion would focus on that content. Under this heading, students may be reflecting on what they have learned or answering one another's questions. Discussion of course procedures is important for helping students cope when they are struggling with technical problems like finding resources, installing software, or navigating the courseware. Most of these contributions could be viewed either as exchange of help, or at least calling out for help. For example, even complaints about confusion regarding course procedures could be viewed as indirect requests for help. Thus, we may loosely consider segments coded this way as help-exchange related contributions. Making social connections also plays a valuable role in community building and provision of emotional support. Since some contributions mix these three foci, we coded this dimension as a set of three binary indicators applied separately to each contribution. In order to be beneficial for content learning, it is important to identify the manner in which content is discussed, and not just that it was mentioned. Thus, we coded a second dimension that distinguishes segments in which reasoning is articulated and therefore made public from those in which it is not. For this, we adopted a previously validated operationalization (Gweon et al., 2013). Each segment was coded either as displaying reasoning or not. With these two distinctions taken together, we can observe help related exchanges focusing on course procedures by looking at the frequency of discussion about course procedures, and we can observe opportunities for substantive reflective discussion about course content by identifying those segments related to course content where reasoning is articulated.

Participation analysis

In order to assess the extent to which our three Communication contexts (e.g., the edX discussion forum, the integrated Bazaar Collaborative Reflection tool and Twitter) engaged different users and in different types of talk, we examined the population of students who participated in each as well as the overlap between pairs of contexts. Ultimately, we are interested both in the distinctions between student populations with these contexts as well as how students connect across platforms in order to learn how these different communication spaces are already interconnected organically. This will inform our future efforts in providing explicit support beyond the borders of single communication platforms.

The Bazaar tool for collaborative reflection was part of an intervention that particularly requested pairs of students to reflect on the course content in a collaborative manner. Consequently, what we hoped to see in the chats was a constructive dialog in which the students revisit the topic of the week, gain a deeper understanding of the subject matter, connect the new knowledge with their personal experiences and exchange ideas. Forums are asynchronous communication tools and posts are not technically restricted to a certain length. Therefore, we expected the forum posts to constitute the largest amount of text compared to chats and tweets. In contrast to public communication platforms, such as Twitter, the target audience of forums is the community of students and instructors, both of which influences the content focus of the posts as well as the way they are written. In contrast to chats and forums, Twitter is an external microblogging service that openly broadcasts to the public. Users can post messages of up to 140 characters on their Twitter stream. At the same time, these messages are displayed in the streams of all followers of the original poster. Tweets can be marked with hashtags, which allows tweets with similar tags to be aggregated. The students in our MOOC were encouraged to use the #dalmooc hashtag in all course related tweets in order to engage other students or interested individuals in a discussion without them having to be followers of the poster. This hashtag was also used to sample the data for the purpose of our analysis. An interesting situation arises from the fact that posting a tweet with the course hashtag reaches both the people who are actively looking out for posts with this tag but also all the followers who are generally interested in the posts from this user but do not necessarily belong to the course in-group.

Findings

Quantitative analysis of participation across communication contexts

In order to quantify the overlap between the sets of users of each communication context, we attempted to map each contribution to an edX account and then compute the intersection of the resulting lists of users from each platform. Forum users can directly be identified in the edX logs and are therefore fully accounted for in our analysis. Bazaar chat users were able to log into the lobby with arbitrary screen names. We therefore use the edX clickstream logs to map each Bazaar user to an edX account. In some cases, it was not possible to compute the match because students did not enter the chat directly through the edX platform. Tweet authors were mapped to edX accounts via voluntary information provided in user profiles from an additional social communication channel integrated in DALMOOC.

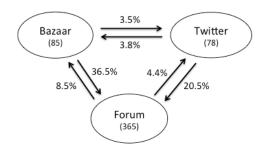


Figure 2. Overlap and distinction between subsets of participants in the Bazaar chats, Twitter, and discussion forums

The diagram in Figure 2 shows the relative overlap in users between pairs of social contexts. The numbers in the ovals represent the number of users whose edX ID could be matched with an ID from the associated context. The links represent the overlap. For example, 20.5% of all Twitter users we could map to edX accounts (78) also posted to the discussion forum while 4.4% of the forum users also posted on Twitter. This analysis suggests that, while we observe some overlap between subpopulations of students who participate in these contexts, the subpopulations are largely distinct.

Quantitative analysis of communication content and type

We hypothesized that students view the purpose of communication in the three contexts in different ways that would influence both the content focus and the nature of the discussion e.g., the extent to which we would observe students articulating their reasoning. We also hypothesized that the content focus of the discussion itself would influence the nature of the discussion as well.

In order to get a sense of the difference in content focus across the three contexts, we performed a chisquared test, with Communication context and Week as the independent variables and each of the binary content focus variables as dependent variables. We also included the interaction between Communication context and Week. There was a main effect of Communication context on concentration of Social segments χ^2 (2, n=675) = 50.6, p < .0001 such that there was a significantly higher concentration of Social talk in the Bazaar chats than the other two contexts. There was a significant interaction between Communication context and Week χ^2 (2, n=675 = 6.42, p < .05 such that in Twitter, there was less social talk in week 2 than in week 1, but this did not generalize to the other two contexts. For Course processes, we observed a significant effect of Week $\chi^2(1,$ n=675) = 6.27, p < .05 such that there was a lower concentration of talk about Course procedures in the second week. We also observed a marginal effect of Communication context χ^2 (2, n=675) = 5,37, p < .05 such that there was somewhat less of a concentration of Course Procedure talk in the discussion forums than in Twitter, with Chat in between the two. There was also a significant interaction between Communication context and Week χ^2 (2, n=675) = 14.7, p < .001 such that the reduction in Course procedures talk was mainly in the Chat, with slight increases in the other two contexts. For Course content, there was a main effect of Week χ^2 (1, n=675 = 14.0, p < .001 such that there was a higher concentration of discussion pertaining to Course context in the second week of the course than the first across contexts. There was a main effect of Communication context χ^2 (2, n=675) = 13.6, p < .005 such that there was a higher concentration of Course content related talk in the Chats and Twitter than the Forums. There was no interaction between Week and Communication context.

Since we observed interactions between Communication context and Week on the three content foci, when we examined the relationships between Communication contexts and concentration of Reasoning, we considered also interactions with Content focus and Week. Thus, each model contains Communication context, Week, one of the Content focus variables, all two way interaction terms, and the three-way interaction term as independent variables. The dependent variable was Reasoning. In all three models, there was a significant effect of Communication context such that there was a higher concentration of Reasoning in the Bazaar Chats than the other two communication contexts. And there was never a significant main effect of Week or interaction between Communication context and Week. A simple model with Communication context as the independent variable and Reasoning as the dependent variable was also significant, so we report that test here χ^2 (2, n=675) = 28.4, p < .0001. There was no significant main effect of Social talk on Reasoning, but there were main effects of the other two binary content focus variables. In the case of Course content χ^2 (1, n=675) = 41.4, p < .0001 there was a higher concentration of reasoning in segments pertaining to Course content than those that did not have this. There was also a significant main effect of Course Procedures χ^2 (1, n=675) = 9.25, p < .05 such that there

was a higher concentration of Reasoning in segments pertaining to Course Procedures than those without. However in this case there was a significant two-way interaction between Week and Course Process χ^2 (1, n=675) = 11.5, p < .001 such that in Week1 there was a higher concentration of Reasoning when Course Process was being discussed, but this was not true in Week2. There was also a significant three way interaction between Week, Course process, and Communication context such that in Week2 there was a higher concentration of Reasoning in the Forums when Course process was discussed than not, but not in Week1.

Qualitative analysis

As we have shown in our quantitative analysis before, chat conversations show the highest average of reflective contributions across all the platforms we observed. An even more interesting difference lies in the way the course content is reflected in the chats. The one-on-one conversations in Bazaar exhibit a strong constructive character where reflective statements are not merely precompiled by each student and then exchanged, they are rather collaboratively constructed in the course of the conversation. The following short excerpt from a longer Bazaar chat shows such an interactive reflection. Rather than each student providing a single complete reply to the agent question, the students construct a joint reply by building on each other's contribution in their own reflection.

- Agent Let's start by looking at the logic of analytics, namely, how we use data to understand the world. Did this resonate with you? What are your concerns with this worldview?"
- Student 1 Well this seems like a great place to start... you will meet a supervisor somewhere in this course i expect... using data is much more reassuring than working on solely intuition... on the other hand, it may be limiting to work with only things you can capture in numbers...
- Student 2 yes, that's my thinking too, often real phenomena are oversimplified with numbers we should gather data also for example affective data etc
- Student 1 but the pattern of working with data can be made more playful, juxtaposing different elements which might appear unrelated, and working to ask questions, as opposed to providing answers... by affective data, what do you mean?
- Student 2 for example, asking about learners emotions during learning

While the segments pertaining to building social connections did not have any specific significance with respect to engendering articulation of reasoning, it is notable the extent to which students use each communication medium to reach out to other for social connection, often with the apparent desire to continue to interact over the course. In the chat, this was especially evident in longer discussions with a lively exchange of ideas.

- Student 2 Very enjoyable session, thanks for the picture... can you give me a link to your blog or some other means of getting back in touch please? maybe we will do some other activity at some point further along? how are you getting along with tableau? do you have data?
- Student 1 @HANDLE at twitter and i also started a course blog http://URL
- Student 2 cool, thanks.... USER@DOMAIN.COM for me...

While the requests to connect expressed in the chats are much more personal and based on a positive exchange of ideas, the forums serve more as a market for people to find other like-minded students with similar interests or from similar backgrounds.

Discussion and current directions

In this paper we have described an analysis of data from one cycle of a design based research process in which we aim to engage students in more intensive discussion based interactions in Massive Open Online courses. We compared across three communication contexts, including Twitter, threaded discussion forums, and synchronous collaborative chats. What we find is that different subpopulations of learners within DALMOOC, an edX MOOC that is the focus of this study, tended to gravitate towards different ones of these contexts. Furthermore, each context was associated with its own unique profile in terms of content focus and the nature of the discussion (i.e., concentration of articulation of reasoning). We see ample evidence within contributions across media pertaining to social connection that these MOOC learners crave continuing social engagement with

other individuals participating in their MOOC course. The analysis suggests that there is value in providing a diverse set of discussion contexts but that it creates a need for greater efforts towards effective bridging between media and channeling of students to pockets of interaction that are potentially of personal benefit. Thus, while providing an eclectic combination of communication contexts has value in terms of engaging a wider variety of MOOC learners, it appears to exacerbate the problem of students who report being overwhelmed by the amount of communication in the forums and having trouble finding the places where there is interaction with the content focus and style they are comfortable with. Together these results suggest a research agenda going forward that seeks to design methods for greater orchestration across media. While some recent work develops social recommendation approaches that operate within single communication media, such as discussion forums (Yang et al., 2014), much work is left to do to develop more effective bridging and integration across media.

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Tools for Tracing the Development of Concepts through Discussions Mediated by a CSCL Environment: A Case Study

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Abstract: This case study explores the use of learning analytics techniques to monitor students' conceptual development evidenced in time-stamped logs of a CSCL environment that provides chat, shared whiteboard, and wiki features. The study was conducted in a graduate level research methods course, which included online assignments that required students to collaboratively discuss questions related to statistical methods in chat sessions and submit their answers through co-authored wiki documents. This paper demonstrates the use of some of the existing learning analytics techniques to develop practical strategies and interfaces for helping instructors to effectively monitor the collaborative knowledge building processes taking place at micro and macro levels. In particular, we demonstrate the use of topic segmentation, tag clouds and concordance analysis for the identification of excerpts where key concepts are discussed by the students.

Keywords: learning analytics, knowledge building, chat, wiki

Introduction

CSCL is a field primarily concerned with the use of information and communication technologies to support learning through collaborative activities. Most CSCL systems offer a variety of communication channels with rich representational affordances, including shared workspaces, text-chat, wiki, discussion board and videoconferencing applications. Such tools enable instructors to support and manage rich learning experiences for their students. These tools also offer unique opportunities for the analysis and assessment of learning interactions as they provide time-stamped logs of all collaborative activities.

Learning occurs in an interactive and dynamic way in CSCL environments, so tracking the collaboration process is an important concern for monitoring and supporting learning activities in CSCL. Assessment of learning in CSCL generally involves two levels; namely product and process assessment. Product assessment involves the evaluation of the final outputs/outcomes to check whether a key skill has been appropriately employed or a specific concept has been mastered, whereas performance assessment is concerned with the quality of the learning process (Retalis, Petropoulou & Lazakidou, 2010). Moreover, assessment in CSCL is also considered as a means to enhance the collaboration process through feedback (Collazos, et al., 2007). For example, providing information on students' own activities can contribute to their awareness and meta-cognitive status, and as a result may facilitate self-regulation of the learning activity (Daradoumis, Martínez-Monés & Xhafa, 2006; Nurmela, Lehtinen & Palonen, 1999). In addition to this, records of learner successes/failures and recommendations for future learning activities based on such records may result in a more structured and efficient learning process (Wang, 2009).

Most CSCL applications automatically record information related to interactions of participants such as messages and documents exchanged (sending and reading timestamps, name of the sender, name of the readers, etc.) in log files (Pozzi, Manca, Persico & Sarti, 2007). However, the sheer volume of data generated by heterogeneous online communication channels, even in the context of a semester-long course, brings practical challenges for the monitoring and facilitation of collaborative learning activities by the educators. The challenges involved with processing this rich body of data forces educators to resort to superficial assessment of learning based on tests, without being able to take into account the micro-level processes of knowledge building which are key to the success of CSCL applications. Therefore, there is a need for tools and strategies for helping educators and researchers to make the best use of this rich data.

The big data phenomenon in business analytics and the increasing amount of data in online educational repositories have led to the emergence of the field of Learning Analytics. According to the definition contributed by the recently established Society for Learning Analytics Research, Learning Analytics is concerned with the measurement, collection, analysis and reporting of data about learners and their contexts of learning, for the purpose of understanding and optimizing learning and the environments in which it occurs (Siemens & Gasevic, 2012). The collection of data and devising analytics to make sense of the trails left by learners is a fundamental concern in this emerging field. Such trails involve information on key aspects of

learning such as information access and use practices learners follow, the social networks they form, the content of interactions they engage with, and the knowledge artifacts they construct in the course of their learning process. Educational data mining and analysis of learning interactions within socio-technical systems are dominant themes in the emerging field of learning analytics (Siemens, 2012; Scherer et al., 2012).

Educational Data Mining (EDM) focuses on devising predictive relationships among features extracted from learner logs to better inform instruction (Baker &Yacef, 2009; Romero & Ventura, 2007; Romero et al., 2010). Automated discovery of learning needs and adapting learning resources to better cater to those needs are key components of the EDM approach. Typical EDM applications involve student modeling where successful as well as risky cases (e.g. a student who is likely to be dropping out) can be automatically detected, and recommender systems that allow students to interact with personalized content based on predictions about their learning needs/styles inferred from their past history (Stamper et al., 2010; Manouselis et al., 2012). Such applications extend the assessment of learning outside individual courses and allow educators to monitor the progress of students as members of a larger learning community (Hung, Hsu & Rice, 2012).

The socio-technical approach focuses on the content and the nature of the learning interactions mediated by learning environments as a systemic whole (Shum & Crick, 2012; Siemens, 2012). Building visualizations of social networks and studying the information flow within those networks with discourse analytic methods are of particular interest in this approach (Ferguson & Shum, 2011, 2012). Such tools are generally intended not only for research use, but also to support teachers' self-reflection on their teaching practice and to inform educational decision makers by providing a broader view of learning activities (Dyckhoff et al., 2012; Govaerts et al., 2012). Design of representations and analytic constructs that facilitate the coordinated analysis of learning traces distributed across individuals, collectivities and media in networked learning environments is another important thread in the socio-technical approach (Suthers & Rosen, 2012). Such tools aim to bring the learning traces distributed across multiple media and sites together to enable the investigation of emergent learning phenomena within a learning community.

In this study we employ a socio-technical approach to analyze the collaborative learning process taking place in a CSCL environment called Virtual Math Teams (VMT) that offers chat and wiki features. More specifically, we explored the use of learning analytic methods to investigate a learning group's conceptual development in a CSCL environment in the context of a semester long statistics course. Conceptual development was investigated according to the knowledge building theory (Scardamalia & Bereiter, 2006) which argues that knowledge is produced through the formation of common goals and negotiation of different perspectives. We attempt to examine how a particular group of students developed their understanding of some the key concepts in statistics during their collaborative activities distributed across multiple interaction spaces and spanning the entire semester. In particular, we aimed to illustrate the use of tag clouds and concordance analysis to locate segments where key statistical concepts were discussed, as part of a process analysis of conceptual development that spans micro and macro levels.

Methods and data

In this study the Virtual Math Teams (VMT) system was used to support and record the collaborative learning activities that took place in the context of a semester long course on research methods and statistics. The VMT system was developed as part of a research project that aims to support collaborative math problem solving activities at a distance (Stahl, 2009). Although the VMT system primarily attempts to serve the mathematics education domain, learning groups can use this platform to engage in collaborative learning activities in other domains as well.

The VMT online environment provides both quasi-synchronous and asynchronous collaboration tools to support collaborative learning activities. The chat component provides support for quasi-synchronous communication for the members of a learning team through the exchange of text-messages. At the same time, chat rooms offer shared whiteboards for drawing and organizing ideas. The chat platform also presents a shared web browser facility, which allows group members to collaboratively browse the web to support their group work. Finally, each chat room has a corresponding wiki page, through which learners can publish their collective findings in the form of co-authored wiki documents. The wiki component is based on MediaWiki.

The study has been conducted in the context of a graduate level Research Methods & Statistics course during 2013-2014 fall term at the Middle East Technical University (METU). There were 21 registered students in the course. Each registered student was assigned to a learning group and seven teams were constructed in total. All teams were required to complete course assignments by collaboratively working online in the VMT environment. That is, learning groups are initially required to perform online chat meetings, then publish their findings as co-authored wiki documents. The online activities were graded as group projects which constituted

half of the total grade students obtained from the course. The remaining half of the grade was based on individual test scores students obtained from two conventional exams.

The assignments cover standard statistical methods including descriptive statistics, exploring data with graphs, correlation/regression methods and methods for testing hypotheses about group differences such as t-test, ANOVA and their non-parametric equivalents. The aim of the online activities was to help students develop their understanding of key statistics concepts through collaborative assignments where they attempted to conduct a specific type of analysis by using the SPSS software. Some concepts such as identification of independent/dependent variables, their scale of measurement, whether variables satisfy parametric assumptions (i.e. normality and homogeneity of variance), the notion of null hypothesis and statistical significance were common to all online activities due to their central role in statistical analysis. Developing a deep understanding of each of these concepts was targeted as learning goals of the course. Our case study focuses on learners' progress in one of these key dimensions during the entire term, namely identifying variables and checking parametric assumptions. The chat logs that were analyzed as part of the case study were obtained from the fourth assignment during the semester, which included the following instructions:

A study of reading comprehension in children compared three methods of instruction. First, all participants' reading comprehension levels were assessed with a pre-test. Then, participants were split into 3 groups, where they were exposed different methods of instruction to develop their reading comprehension skills. Finally, all group members were given a post-test that is comparable to the pre-test in terms of content. The data for the study is stored in reading.sav file.

- 1. Identify the dependent and independent variables of this study. At what level of scale each variable is measured?
- 2. Are the dependent variables normally distributed? Perform the appropriate tests in SPSS and report their results (Note: use the appropriate group level for these tests.)
- 3. Focus on the pre-test results only. Draw a bar chart with 95% confidence intervals. Is there a difference among the groups? Which test would be appropriate to test whether there is a statistically significant difference among the groups and why? What is the null hypothesis? Do the test and report the test results (you should use the reporting guidelines in the book). If there is an overall difference, which pair of groups differ from each other? Again, explain what statistical test you are using to make that argument.
- 4. Next, focus on the post-test results. Draw a bar chart with 95% confidence intervals. Is there a difference among the groups? Which test would be appropriate to test whether there is a statistically significant difference among the groups and why? What is the null hypothesis? Do the test and report the test results (you should use the reporting guidelines in the book). If there is an overall difference, which pair of groups differ from each other? Again, explain what statistical test you are using to make that argument.
- 5. Finally, focus on each instruction group separately. Which test should you use to compare the difference between the pre and post test scores of each student in each instruction group? Do the appropriate test(s) and report the results in the formal reporting format.

Data collection

This study focuses on excerpts obtained from the online sessions of a single team in this corpus. The participants' actions in the chat environment were recorded as chat log files, which were automatically logged by the VMT system. Teams used a single chat room for each assignment, so one chat log file was generated for each group. The chat log contained the author, date, start time, post time, duration, and event type for each action entry. Remaining columns are allocated for indicating chat messages and other activities of students (e.g. awareness messages such as user is typing, drawing on the whiteboard etc.).

Chat discussions continue with learners' submission of solutions as wiki content, which are represented with screenshots in Figure 1. Wiki activities of learners are listed in the "View History" page and listed from initial to recent one. Each wiki activity is tagged with its author and time information. Successive activities can be compared to identify learners' editions and removals related to the wiki content. The VMT also provides Wiki activities in textual format, hence facilitates the analysis of the evolution of the wiki content.

Data analysis

After collecting data, we consider the following steps for the analysis of chat logs:

Segmentation Analysis

- Removal of stop words
- Use of Tag Clouds to identify recurrent concepts
- Concordance Analysis to identify the context of concepts
- Interaction Analysis of episodes for tracking learners' development of concepts

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the second of the from stand for the from stan	Illessage:	Are the dipendent excellent commany distributed? Do they satisfy homogeneity of variance? Reform the appropriate tasks in SPS3 and report here result (pluce use the appropriate proje here for these tasks in VL subsolut keep norm of the comparisons you will do in the rest quantitional tasks, we can any that for pre-keet only the 'task group is significantly different. (p)/sioning at the task of investigat balance, we can any that for pre-keet only the 'task group is significantly distributed (p-/56) - 93, pc/25 bein a normal distribution. However, for the post test condition, all the groups are normally distributed (p-/56).

Figure 1. VMT chat and wiki components

Segmentation analysis aims to capture how participants organize their chat interaction into long sequences (i.e. chunks of activity). For this purpose, chat logs are investigated to identify activity boundaries where new activities are initiated and current activities are terminated or suspended. That is, transitions where learners either (1) close one activity to initiate a new one, or (2) temporarily suspend an ongoing activity and start a temporary one as an insertion sequence, are identified by investigating topic/activity change markers (Zemel, Xhafa & Cakir, 2007). As a result, chat logs are organized into segments.

Next, stop words (e.g. words that provide no content such as prepositions, conjunctions, determiners) are eliminated from chat logs in order to prepare the data for further analysis. Then, chat logs are subjected to content analysis to identify recurrent keywords in that session. In particular, tag clouds are computed for preprocessed log files where the size of the word indicates its frequency. In our study, tag clouds are employed to identify the statistical concepts learners discuss during their chat sessions.

Thirdly, concordance analysis is employed to identify the context in which key terms of interest occurred in the chat logs. In this case study, we focus on tracking the evolution of a group of learners' understanding of variable types and parametric assumptions. Once we identify the contexts in which key statistics concepts were mentioned by the team, we focus on the sequential organization of chat messages and whiteboard actions in that episode to observe how learners referred to and made use of these concepts.

Finally, the wiki content is analyzed as a reflection of the discussions that took place during the team's chat session. Wiki content constituted the final deliverable submitted by the team, so its content is organized to be read as a summary of the team's findings. The way team members use key concepts in their wiki pages are further analyzed to trace their conceptual development.

Results

The team consists of three students, whose demographic characteristics are provided in the Table 1.

Subject Handle	A_S	G_C	Y_A
Age	Over 29	22-29	Over 29
Gender	Male	Female	Male
Grade	PhD	Masters	Masters
Undergraduate major	Physics	Foreign Language Education	Electric and Electronics Eng.
Graduate major	Biomedical Engineering	Cognitive Science	Cognitive Science
Current GPA	3.00-3.50	3.00-3.50	3.00-3.50

Table 1: Demographic characteristics of students

The team has performed a series of online meetings while working on their group assignments. In this study, we provide results from their fourth assignment to illustrate our analysis. The chat log for the fourth assignment consists of 376 chat lines. The task description was provided in the methods section.

Chat segmentation results

Chat logs of the assignment have been quickly investigated to identify specific discussion topics. The team has performed three online chat meetings and considered various topics during these sessions. The topics mainly consist of coordination issues and learners' discussions related to the assignment. We consider segments related to the assignment in the subsequent steps of our analysis.

Key concepts the team considered

The next chat processing step aims to explore key concepts that the team has employed during their online collaborative studies. For this purpose, we mainly focus on segments that capture the discussion of the members on the assignment. These task-related logs, which are identified during the segmentation analysis step, belong to two different online meeting of the team. In parallel to our purpose, we have employed tag clouds on these task-related logs to identify concepts that the team considered while they were collaboratively solving the questions involved in the assignment. We used the TagCrowd to obtain the two tag clouds displayed in Figure 2 that represent the most frequently observed key terms in the task-related segments of both logs.



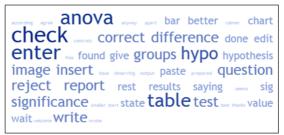


Figure 2. Key concepts discussed in the group meetings

In this case study, we focus on the learners' discussion of two specific statistical concepts – variables and normality test. These two concepts frequently occurred in the first tag cloud. For instance, the "normality" concept is reflected with 'normality' and 'test' keywords together with their large sizes. Similarly, the "variables" concept is identified by 'dependent' and 'variable' key words.

Concordance analysis

Concordance analysis is applied to indicate locations of the keywords within the chat logs. Compared to segmented excerpts, the lines obtained from concordance analysis are minimal and more specific. For instance, the team's task related activities are identified as segmented excerpts, whereas chat lines related to learners' understanding of the variable concept are obtained through the concordance analysis.

The results of the concordance analysis demonstrated that the "variable" concept was discussed between chat lines 33 and 36, and the "normality test" was discussed between chat lines 98 and 137. Although each sentence within these chat lines doesn't consist of the keywords, we consider all messages since they are components of an ongoing interaction and have pragmatic and semantic relationships with the lines containing the keywords. Simply ignoring the lines that do not include the keywords brings problems of intelligibility, since chat unfolds sequentially and the meaning of each utterance need to be analyzed within this sequential context.

Learners' development of concepts

Once the relevant excerpts are obtained through segmentation, tag cloud and concordance analysis steps, we focus on the interactional content where the "variables" and "normality test" concepts were discussed by the team. Our purpose is to understand how learners made progress throughout chat activities while working on these concepts.

Variables

The excerpt obtained from the concordance analysis related to the variables concept is provided below.

- 1. A_S: we can start to discuss dependent and independent variables and the level of scale
- 2. G_C: i think Pre test and Post test are dependent (ratio); method groups are independent (nominal-categorical) variables.?

- 3. Y A: That is exactly my opinion too.
- 4. A_S: I agree with your opinions

A_S initiated the discussion about the "variables" concept with his remark in line 1, possibly in response to the first question in the assignment. This is taken up by G_C in line 2, where she proposed the test scores as the dependent and the group categories as the independent variables. She also proposed that test scores are measured at the ratio level and group is a nominal-categorical variable. In the next two lines, Y_A and A_S agreed with G_C. The team quickly came to an agreement around G_C's proposal. Note that this was the team's fourth assignment where they answered similar questions for the previous three assignments. Coming to an agreed answer for the same question took more time and turns in those previous cases, so the team seemed to have progressed in detecting and categorizing variables involved in a given research design description. However, one could criticize the argument that test scores are measured at the ratio scale, since a score of 0 does not necessarily imply absence of reading comprehension skills.

Normality test

Initial lines of the excerpt obtained from the concordance analysis are provided below.

1. Y_A:	so about the normality tests
2. Y_A:	I've got some results from the explore menu item
3. Y_A:	some look normal, some not.
4. G_C:	sorry before we move on, did you split the file?
5. A_S:	actually I splitted the file but I got weird results I'm doing somethings
	wrong
6. Y_A:	no i didn't. should I?
7. G_C:	no, i just wanted to be sure
8. A_S:	I think its better to split hocam
9. A_S:	how did you do it without split Y_A?

Before the first chat message, Y A shared the results of his tests of normality in the whiteboard area. He then indicates in the first three lines that he applied the normality tests by using the Explore feature of SPSS, and found that some variables were normally distributed, whereas others were not. Through these chat messages Y A reported his initial finding about the distribution of data, without specifically identifying the normal and non-normal cases. In line 4, G C asks whether Y A had considered splitting the data before testing for normality. Next, A S comments that he obtained weird results when he tried splitting the data, and states that he had probably done something wrong. In the next line, Y A responds to G C that he didn't split the file, and asked if he should had done so. G C's response in the next line indicates that she did not see this as a necessity, but she was mainly reminding her teammates about a possible issue. In line 8, A S argues that it is better to split (hocam is a Turkish term used as a colloquial way to address a fellow student or colleague) and asks Y_A how he did the analysis without splitting. In the following conversation (not provided in the transcript) Y_A provided a summary of his steps where he explained how he conducted the normality test by using the explore menu in SPSS by defining pre-test and post-test as dependent variables. This short exchange among the team members indicate that they took issue with an important concern, namely identifying the correct level to check for the normality assumption. The problem statement states that there are three independent groups in the experiment, whose scores should be tested for normality separately. Splitting the data set is one way to achieve this in SPSS depending on how the data is organized. This discussion provides evidence that the team members are aware of finding the appropriate level to apply the test, but they have neither justified nor demonstrated this explicitly.

In the segment identified by the concordance analysis, Y_A shared the output he obtained from SPSS for the Kolmogorov-Smirnov (K-S) and the Shapiro-Wilks (S-W) tests. Y_A stated that group-2 has non-normal distribution in both pre and post test cases according to the K-S test, whereas only group-1's pre-test scores are not normally distributed according to the S-W test. Then, Y_A asked others whether they agree with these results. G_C stated that she applied the test and found the same results as Y_A. Previously G_C couldn't produce results in SPSS. Y_A's statements seemed to help G_C to replicate the analysis on her computer.

Next, the team discussed what they should do with the variables that violate normality. Y_A argued that all the scores could be considered fairly normal, since the sample size of 22 was not so small and the q-q plots looked fairly on the diagonal. G_C agreed with Y_A. Then, A_S reminded the team that when the sample

size is less than 30, S-W is a more conservative test of normality, and argued that S-W could be the more reliable test in this case. During this discussion it turned out that the reason why A_S found weird results was due to an incorrect splitting he applied on the data. Y_A's comments helped A_S correct his analysis.

In the following part of the discussion, Y_A proposed that the deviation from normality in the variable of concern was due to an outlier, which he noticed on the q-q plot, and wondered if that could be a typo in the data. G_C agreed on the presence of an outlier but argued it could be a genuine data point, as no information about minimum and maximum possible scores were given in the problem statement. The team then agreed that the outlier was not to be treated as a typo. A_S asked if they will ignore the outlier and consider pre-test scores of group-1 as normal. Y_A proposed to explain the significance of the S-W test due to the presence of this outlier score, and continue with a parametric test for subsequent analysis. G_C and A_S's agreement concluded the discussion on checking the assumption of normality in this log.

Wiki reflection

According to the wiki logs, G_C wrote the results about variables as follows: "Pre test and Post test are dependent (ratio); method groups are independent (nominal-categorical) variables. "Y_A shared the results of the normality tests as a table, whereas G_C contributed the interpretation "By looking at the tests of normality table, we can say that for pre-test only the 1st group is significantly different (D(22)=,91, p<,05) from a normal distribution. However, for the post test condition, all the groups are normally distributed (p>,05)".

The wiki summary does not capture all the details of the team's chat discussion. The team stated their answer for the variable types in the same way as it was articulated in one of the chat messages. They presented the normality analysis with the correct groupings, but provided the standard interpretation of the K-S test results. The wiki posting for this particular question seem to suggest that the group members changed their mind about treating the pre-test score of group-1 as normally distributed. In particular, they didn't mention their noticing about the outlier and its effect on the normality test. However, in the remaining parts of the question, the team employed a parametric test to complete their analysis, which seemed to be a consequence of this discussion.

Discussion and conclusion

A significant advantage of CSCL environments is that they provide system logs that record details of interactions experienced among students. Since these logs capture instances where learners ask questions, look for information and make reasoning together, learning becomes visible to the instructors. The growing use of computer-mediated communication channels such as social networking, chat, instant messengers and wikis as components of CSCL applications has resulted in large repositories of such learning interactions. Although CSCL tools offer advantages to eliminate the student isolation issue, such environments also result in some methodological and pedagogical challenges. For example, analyzing hundreds of lines of collaborative interactions of student teams is a time consuming task for instructors. Therefore, instructors generally focus on learning outputs while evaluating learner performance in CSCL environments. In this kind of evaluation, each team member is often assumed to equally contribute to the final deliverable, and each obtains the same grade as a result of evaluation. Yet, dividing students into groups and requiring them to collaborate do not simply result in equal participation and effective discussion. Thus, a detailed monitoring of the collaboration process is necessary to support teachers to perform a fair assessment of group work and provide support when needed (Wang, 2009).

In this study, we aimed to bring together basic ideas from text-mining and interaction analysis methods to prototype an interface that will help instructors follow the conceptual development of their students with respect to the specific learning goals of their course. For that purpose, we used tokens and phrases that signal a change in the course of the discussion as a basis for the initial segmentation of the chat data. This step provided the much-needed pre-processing to improve the representative power of the tag-cloud analysis performed in the next stage. The keywords deemed important by the instructor based on the course goals can be then used at this point to navigate through chat and wiki logs. Concordance analysis aims to help teachers identify those interactional episodes where the teams discussed the key concepts. The case study summarized above allowed us to observe how a team of students discussed key issues involved with identifying variable types and their scale of measurement as well as their distributions. Capturing such instances across multiple log files would give the teacher a much better view of the progression of ideas across multiple sessions and teams, as well as the difficulties students might be having with specific concepts and methods. In future work we are planning to automate more of the key steps in the presented process in an effort to develop a dashboard interface for instructors where they can visualize the data at different granularities and zoom in/out of collaboration logs depending on the level of analysis they deem relevant for their educational goals. For instance, linguistic markers used for initiating changes in the course of a discussion in chat can be used to mark potential segment boundaries in an automated manner. Since chat data is noisy with missing phrases and incorrect spellings, it is in general difficult to employ natural language processing techniques on chat data. However, segmentation can be improved further by considering word repetition patterns and coherence indicators for candidate segments. However, such techniques will inevitably fall short in dealing with the complexity of the meaning making processes taking place in the logs. Therefore, our main goal will be to support the teachers with practical analytics and navigational tools so that they can effectively trace the fragments of students' knowledge building discourse distributed in many components of modern CSCL systems.

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Scaffolding Scientific Epistemologies through Knowledge-Building Discourse and Epistemic Reflection

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Abstract: This study investigated how elementary-school children's science epistemologies can be fostered in a CSCL knowledge-building environment focusing on epistemic inquiry and reflection. Two classes of fifth graders in Hong Kong participated in a unit of electricity study. The design involves students engaging in scientific inquiry, pursuing ideas on Knowledge Forum®, and making epistemic reflection about the inquiry process. A key design theme involves children reflecting on their inquiry in relation to scientific practice and collective theory building. Analyses indicate that online discourse moves reflecting epistemic inquiry (problem-centred uptake and theory building) were correlated with post-test epistemic and conceptual understanding. Classroom and interview analyses showed how students' epistemic practice (e.g., theory revision) and epistemic reflection (connecting their own inquiry and scientists' inquiry) might have influenced their epistemic development. Implications of how children develop scientific epistemologies supported by epistemic inquiry, discourse and reflection in a knowledge-building environment are discussed.

Keywords: knowledge building, CSCL discourse, epistemic views of science, scientific inquiry

Helping students understand the nature of science and scientific inquiry has always been the central focus of science education. A growing number of studies have been conducted to understand students' epistemic views of science, and its relation to other cognitions (Stathopoulou & Vosniadou, 2007; Tsai & Liu, 2005). However, few studies have examined how it can be fostered, especially how it can be fostered in computer-supported collaborative learning (CSCL) environments. The purpose of this study is to examine how a computer-supported knowledge-building environment may facilitate students' scientific epistemologies and knowledge advances.

Theoretical perspective

Epistemic views of science and CSCL

Epistemic cognition is individual's understanding about the nature of knowledge and knowing (Chinn, Buckland, & Samarapungavan, 2011). There are different lines of research conceptualizing epistemic cognition (Hofer & Pintrich, 1997; Lederman et al., 2002; Schommer, 1990), among which one line focused on the ideadriven and constructive nature of science. Carey et al. (1989) initiated this line of research and identified three general levels of epistemic understanding among seventh grade students, ranging from viewing science as concrete activity to viewing it as an idea driven process and as construction of ever-deeper explanations of the natural world. Later Smith et al. (2000) made a more elaborate study of sixth graders' epistemologies of science, and differentiated different aspects of the epistemology (e.g., goals of science, the nature of scientific questions, etc.). Chuy, Scardamalia and colleagues (2010) further developed the interview protocol, emphasizing on theoretical progress. The epistemic cognition framework this study used was based on these previous studies and examined how students understand science as an idea driven process, and it further extends it to the social aspect, and focuses on how students understand the collective and progressive nature of scientific progress.

Many studies have designed computer supported collaborative learning (CSCL) environments to support students' scientific inquiry with some indicating that the epistemological design of those environments could influence the nature of students' inquiry process (Clark, Weinberger, Jucks, Spitulnik, & Wallace, 2003). For example, Tan et al. (2005) noted the change of students' epistemology and scientific inquiry skills in a computer supported collaborative learning environment. Underlying these designs and technologies is the emphasis on role of epistemology and that scientific knowledge is socially constructed and advances in a progressive manner. However, how students understand science's progressive and socially constructed process and how it relates to their scientific inquiry practice is not well examined. We argue here that it is important to examine how individuals understand science as a collective theory building process and how they understand its social and progressive nature, as this may help to explain students' collaborative knowledge construction

process in CSCL environments. It could also help us to reflect on and improve the epistemic principles of the technology used to support students' collaborative inquiry.

Computer supported knowledge building

As one of computer-supported inquiry-based models in education, knowledge building has attracted much of the attention in the recent years (Scardamalia & Bereiter, 2006). One essential aspect of knowledge building is students taking collective cognitive responsibility for community knowledge advancement. In knowledge building, ideas are viewed as conceptual artifacts that can be constantly improved. To support such knowledge work, Knowledge Forum® (KF) has been created as a communal place where ideas can be worked on in various ways (e.g., linked to other ideas, be visualized with structures, be highlighted with graphs, and be revised, etc.). Scaffolds are also provided for students to work towards knowledge building: "I need to understand", "my theory", "new information", "a better theory", "putting our knowledge together", etc. These epistemic prompt may help develop students' epistemic understanding about the collective theory building nature of science.

A growing number of studies have been conducted to examine the design and effects of knowledge building on students' science learning (Hakkarainen, 2004; Lee, Chan, & van Aalst, 2006; Oshima & Scardamalia, 1996). Results have shown the role of knowledge building discourse and classroom dynamics on students' understanding (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). However, few studies have explicitly relate knowledge building with students' scientific epistemologies drawing upon online and offline data (Chan & Lam, 2010; Chuy et al., 2010). Therefore, the purpose of the current study was to address this issue, and to examine how knowledge building may foster students' epistemic and conceptual growth. This paper is based on a large project that examines the design, processes and effects of a knowledge-building environment on students' epistemic and conceptual understanding. In a preliminary study (Lin & Chan, 2014), we have reported on the quantitative findings indicating that knowledge-building students improved more on their epistemic and conceptual understanding than the comparison group. This study draws upon the data from Knowledge Forum, classroom observation, and interviews to examine how the design might have fostered students' epistemic growth and knowledge advances. Specifically, three research questions are addressed: (1) How do Knowledge Forum inquiry and discourse relate to students' epistemic and conceptual understanding; (2) How does classroom dynamics including discourse and reflection facilitate students' epistemic growth; (3) How do students understand their own and scientist inquiry reflected in their interviews? -

Methods

Participants and context

As noted above, this is part of a large design study. Four classes of fifth graders in Hong Kong participated in the study, among which two classes (n=52) were engaged in knowledge building and epistemic reflection, for comparison, the other two (n=50) were taught with regular inquiry-based approach. This paper focuses on the knowledge-building classes.

Designing the knowledge-building environment: Students as little scientists

The key design is to help students work like little scientists engaging in epistemic inquiry and reflecting on the inquiry process collectively. Students pursued ideas (e.g., pose questions/explanation; revise idea) on Knowledge Forum (KF), tested their ideas in experiments; and reflected on their inquiry process integrating online and offline discourse. The specific designs include: (1) *Activate prior epistemic and conceptual understanding:* Students discussed their initial ideas about electricity and what scientists do in the classroom (2) *Authentic problems and inquiry:* Students watched a video on experiments about lemon juice/ salt water conducting electricity, conducted hands-on experiments to test conductivity of different materials; posed wonderment questions and put their ideas and questions on KF; scaffolds were provided (e.g., "*I need to understand*", "*my theory*", "*new information*") to facilitate theory building. (3) *Deepen inquiry through experiments and classroom epistemic talk:* Students worked in groups to design experiments to test their KF ideas; they reflected on their forum discourse and inquiry and wrote on KF their epistemic understanding; (4) Connect students' inquiry with scientists' inquiry through epistemic reflection. Students were scaffold to reflect on the relations between their own inquiry and scientists' inquiry (5) *Knowledge building reflection:* Students worke portfolio notes on KF to reflect on their collective discourse with knowledge building principles.

Analyses and results

The previous paper has reported on preliminary analyses; students' epistemic views of science were measured with a written test developed from previous studies (Carey et al., 1989; Lederman & Ko, 2004; Smith et al.,

2000). Four components were identified to characterize epistemic views: (1) role of idea, (2) theory building (3) theory-fact understanding, and (4) social process of scientific progress. The general pattern ranges from viewing science as concrete activities to seeing it as collective theory building process. Quantitative analysis indicated that the knowledge-building group improved more in their epistemic and conceptual understanding than the comparison group (Lin & Chan, 2014). While quantitative findings show positive effects, questions remain as to how the designed environment facilitated students' epistemic and conceptual growth. This study specifically examined how Knowledge Forum inquiry (online) and classroom inquiry and dynamics (offline) might contribute to the change. Students' focus group interviews were also examined to explain the change processes.

Q1: Examining Knowledge Forum discourse and relations with epistemic and conceptual understanding

Among the two knowledge-building classes, Class 1 students on average wrote 13.2 notes, linked 66.7% of the notes, and read 30.4% of the total notes. Class 2 students on average wrote 7.5 notes, linked 52.7% and read 32% of the notes; these indices are comparable to those in knowledge building research (Lee et al., 2006). To characterize the socio-cognitive-epistemic aspects of knowledge building discourse, analysis of Knowledge Forum notes was conducted both on thread and individual note levels. The notes were first parsed into threads, and coded into three patterns: knowledge sharing (sharing of information), knowledge construction (interacting to construct understanding), and knowledge building (working to extend and create knowledge) (van Aalst, 2009). The following excerpt shows an example of a knowledge building thread.

Student#	Note content
5a03	I don't understand]: Why can salt conduct electricity?
5a34	Because salt is a kind of electrolyte
5a16	[A better theory]: after the experiment, we found that both salt and salt water can not conduct electricity
5a20	[You theory can not explain]: After this experiment, we found that salt can not conduct electricity, but salt water can. Salt water is NaCl, it is ionic compound, and there are free electrons or ions in it. Therefore it can conduct electricity.
5a34	[A better theory]: because salt consists of Na+ and C-, Na+ is metal ion, can allow free electron pass through. Na+ and K+ transmit as nerves in our brain, therefore salt can conduct electricity.
5a31	[I don't understand]: can anything that does not contain Na+ conduct electricity?
5a11	[Your theory cannot explain]: Salt is a kind of metal ion, and can conduct electricity; salt water is a kind of soluble liquid with salt. Any liquid that can dissolve salt can conduct electricity, because there are free electrons in it, and it is called electrolyte.
	[My theory]: any liquor with electrolyte can conduct electricity.

[My theory]: any liquor with electrolyte can conduct electricity.

As the excerpt shows, student 5a03 started with an alternative conception (misconception), asking why salt conduct electricity. 5a34 proposed a theory that salt is a kind of electrolyte. Then 5a16 used the evidence from the experiment to question her classmates' conception noting salt cannot conduct electricity, but he also included a misconception noting salt water cannot conduct electricity. 5a20 noted the problem and explained why salt water can conduct electricity ("Salt water is NaCl, it is ionic compound ... there are free electrons or ions.. it can conduct electricity"). However, 5a34 then proposed a theory to explain why salt conduct electricity. The idea of Na+ from 5a20 and 5a34 brought about an emergent question from 5a31 wondering if anything without Na+ can conduct electricity. That led to 5a11 proposing another theory explaining why salt water conduct electricity, he used the example of salt water conducting electricity to generate the principle that "Any liquid that can dissolve salt can conduct electricity, because there are free electrons in it, and it is called electrolyte." Further, he came up with a new theory that "any liquor with electrolyte can conduct electricity." This example showed how this group of young students worked collectively at something well beyond their curriculum: they devoted theory-building and knowledge-creation efforts to pose questions and explanations and to continually revise earlier ideas; they provided explanations about why salt water conduct electricity and gradually developed a more abstract theory; new information was embedded along the discussion; misconceptions existed but continually revised. This example showed how study collectively built ideas on Knowledge Forum to advance their community knowledge.

Notes within the conceptual threads were also analyzed quantitatively for understanding discourse moves. Premised on knowledge building theory, two components were identified: *Problem-centred uptake* and *Theory-Building*. (1) *Problem-centred uptake* discourse moves refer to how coherently the idea was connected to previous idea to address the original problem and also for deepening the inquiry. Four levels were coded: At level 1, the note makes no/weak connections to the previous note. At level 2, there is vague connection; the response is not essential for solving the problem (e.g., ask for elaboration). At level 3, the note has reasonable connection in terms of solving the problem (e.g., move discussion back to the problem; rise above; ask deepening question). (2) *Theory building* includes discourse moves that illustrate efforts to build theory, including initiating inquiry, sustaining inquiry, theorizing (explanation), responding, and using social-cognitive conflict to spark progress (see Table 1).

Code	Description
Initiate inquiry	Initiates a thread; starts with a question or a statement
Theorizing (low)	Provides simple explanation; intuitively try to provide reasons for a phenomenon.
Theorizing (high)	Constructs deep explanation; search for abstract mechanism-process, or the complex
	observable mechanism of a phenomenon, incorporated with new information/evidence
Sustain inquiry (low)	Asks simple or superficial questions for elaboration or explanation.
Sustain inquiry (high)	Asks deepening question that sustain inquiry for progressive problem solving e.g., ask
	for explaining the mechanism; emergent questions
Response (low)	Responds to the previous notes with simple factual word or statement (differentiated from explanation that tries to theorize for mechanism).
Response (high)	Reasonable and elaborated responses to the previous notes, embedded with new
Response (mgn)	information (differentiated from explanation that tries to theorize for mechanism).
Social cognitive conflict	Identifies problems/misconceptions; questions ideas under discussion to move forward
Non-build on	Scattered notes without any build on; or other irrelevant note

Table 1: Coding scheme for theory building effort

Correlation analysis was conducted to examine the relations of discourse moves with students' epistemic and conceptual understanding (Table 2). Forum participation was examined using a tool called Analytic Toolkit and different indices (e.g., read, write, scaffolds) were combined using factor analyses (Lee et al., 2006). Analyses showed that students post-test conceptual understanding was correlated with post-test epistemic cognition, KF participation, KF high problem centred uptake (level 3+level4), and KF explanation and response (high). As well, students' post-test epistemic cognition was correlated with KF high problem centred uptake, KF explanation and response (high), and KF sustain inquiry. These results suggest that students' problem-centred uptake and theory building moves are related to their epistemic and conceptual understanding.

Table 2 Correlation amon	g KF discourse,	post concept	tual understanding	, and post	epistemic views (n=52)

	1	2	3	4	5	6	7	8
1.Post-test conceptual								
2.Post-test epistemic	.489**							
3.KF participation (ATK)	.320*	0.247						
4.KF high problem-centred uptake	.378**	.339*	.698**					
5.KF initiate inquiry	0.126	0.08	0.275	0.24				
6.KF explanation & response (high)	.412**	.292*	.728**	.822**	0.185			
7.KF sustain inquiry	0.168	.289*	.492**	.812**	0.228	.463**		
8.KF socio-cognitive conflict	0.218	0.175	.315*	.415**	0.114	0.19	.482**	
9.KF nonbuid on	-0.241	-0.091	.276*	-0.035	0.201	-0.043	0.174	-0.043

Note: *p<.05; **p<.01

Q2: Scaffolding Epistemic Discourse and Reflection in the Classroom

This study also analyzed key themes emerging in the knowledge building classroom reflecting students' epistemic inquiry and practice; online and offline discourse were integrated. There are many key events and the selection was guided by framework emphasizing epistemic reflection and theory building.

Epistemic inquiry activating prior knowledge and asking questions

In the knowledge-building classroom, from the start, the focus is about letting students develop practice of raising questions and constructing explanations and improving on these ideas. Students asked various questions

about electricity (e.g., *why does water conduct electricity? What makes conductor conduct electricity?*). Question generation is key to scientific inquiry/progress; students posed problems on KF and in class to acculturate students into epistemic practice of problem-centred inquiry. The teacher also scaffolded students to consider their views of science, and to link their experiments with scientific practice and theory building.

Theory revision in scientific and epistemic inquiry

The teacher scaffolded students to understand role of idea and theory revision from their own inquiry experience. To test the various ideas on Knowledge Forum, students worked in different groups to design experiments (each group worked on their question, theory, hypothesis and design in a piece of poster). One group observed that water does not conduct electricity, and they proposed a theory (explanation) "*it is related to the materials of the cup; the cup that holds water is plastic, which is insulator, and so the water in the cup cannot conduct electricity*". The teacher worked with this group to test their 'cup theory'. They came up with the idea of testing the conductivity of water held by different cups (plastic, wooden, and metal). The experiment was conducted and the teacher initiated an epistemic discussion with the whole class after that.

SW: we found that even we put the water in different cups, the brightness of light is similar.

T(Teacher): how are these findings different from the group's hypotheses?

- SW: It means that the hypotheses about the plastic cup & wooden cup were wrong (they hypothesized that the water held by plastic and wood cup cannot conduct electricity).
- T: why are the hypotheses wrong**Do you still remember the theory?**....
- SC: we observed that the water in the wood cup can make the light a little bit brighter; it may be related to the impurity in the wood.
- SG: the light showed similar brightness with whatever cups, it means that...
- Ss: it has nothing to do with the cups...
- T: I appreciate SC mentioned something new, he mentioned ... [The discussion continued...]
- T: ...now suppose you are the scientists, **how would you revise your theory**[Ss wrote on papers]
- SY: it is related to the amount of the water
- SM: it is related to the different kinds of water, such as running water, distilled water...

This example illustrates how different ideas develop in classroom/KF discussion with students coming up with their ideas (cup theory) tested in experiments, and how students began to see that their theory (idea) need to be tested and revised similar to scientific practice. Another interesting theme is that while the teacher expected students to discuss based on the central problem (materials of cups), one student SC mentioned some unexpected results and proposed a new theory to explain the phenomenon (*the light of the wood cup is a little bit brighter, maybe related to impurity in the wood*), which pointed to experimental error and possibly a new direction for further inquiry. The process was similar to the emerging process of the mature scientific inquiry, which involves theory testing and theory revision. This experience might have influenced how students understand science as a theory revision and theory building process.

Epistemic inquiry into their and scientists' knowledge-construction processes.

In this knowledge building classroom, to scaffold students to engage in scientific and epistemic inquiry, students were involved in designing, testing ideas, and reflecting on their inquiry. Students wrote on the poster (Figure 1) their experimental design (prompts: problem, theory, hypothesis, design). In the same poster, they also wrote their views of science (prompts; what is science? Are we investigating like scientists? And how do scientists construct knowledge?). The following excerpt showed an example of the epistemic discussion:

- Student A: how do scientists construct knowledge?
- Student B: with their mind
- Student Y: by doing experiment
- Student W: is that doing experiment can bring us knowledge? I did so many experiments, why didn't I not construct knowledge?
- Student Y: because you just do experiment.
- Student W: but you said scientists do experiment to construct knowledge....

- Student B: by discussion....discuss problems..
- Student A: are we working like scientists?
- Student Y: do experiment, and constantly doing inquiry.
- Student B: we will investigate problems we don't understand.

This example illustrates how epistemic talk, or having students explicitly discuss how science knowledge is created, might help them understand more about their own inquiry and nature of science. These children started with a naïve or impoverished idea (scientists construct knowledge with their mind), and gradually came to understand more about the role of discourse and experiment for constructing knowledge. Though the discourse is still preliminary, children might begin to see more about the constructive nature of science and need for sustained inquiry to tackle problems they didn't understand.

Using an epistemic model to reflect on collective theory building

One of the culminating activities involves using an epistemic model to scaffold epistemic reflection: The teacher showed students a visual representation (Little Scientists Worksheet) that illustrated a simplified model of the structure of scientists' collective inquiry. As Figure 2 shows, Scientist A asks a question, proposes theory A to address the research problem; Scientist B questions scientist A's theory and proposes theory B; Scientist C further improves scientist A's theory and proposes theory C; Scientist D synthesizes scientist B and scientist C's theory into theory D. Different arrows are connected to indicate inquiry is an ongoing process. Students were asked to *indicate* elements that were similar to what they have experienced. The teacher initiated an epistemic discussion among students, as the following example shows.

- T: You have played different parts... in your inquiry. Many of you asked questions and proposed theories, um..like scientist A... ...so [what about] scientist B? Is there no need for Scientist B?
- Ss: no, we need scientist B and C to question [them], so that we can improve the theory....
- T:None of you mentioned scientist D...?
- SW: ...[we need] scientist D... could combine scientist B and C's theories, and make a better theory

This example suggests how the prototypes of different scientists, in the form of an epistemic model, might help students to see the similarity between what they do and what scientist do illustrated in the model, and therefore might prompt students to develop a better epistemic understanding about scientists' inquiry process.



Figure 1. Group poster

Figure 2. Little Scientists worksheet

Q3: Examining students epistemic understanding via interviews

From viewing science as inventing concrete things to viewing it as theory building process

Consistent with the quantitative findings about the impact of the designed environment on students' epistemic change, qualitative analysis of students' focus group interview also showed that many students initially thought of scientists as only doing experiments or inventing things, but that, after the program, they started to understand the role of idea and social cognitive conflict in science. For example, student CFM said:

I used to think that scientists only researched something to help people, but after this semester (after knowledge building), now I understand that scientists not only research something, they will ask questions, which people don't know yet... then other scientists will continue to ask

him why is that... I thought scientists only invented things, and never thought they proposed theories.

For the students who already had some understanding of the role of idea in science, they mentioned that they had further realized how scientists work together to improve knowledge, and spontaneously connected it to what they did in Knowledge Forum, as one student reflected:

"Before, I thought scientists just investigated something, and then made a theory. Now I understand how scientists push each other forward...(Can you explain what you mean by 'push each other forward').. Just like how we ask questions in Knowledge Forum, then we answer each other's questions. Scientists also have their own questions, then other scientists or they themselves may find the answers, then there will be more questions...and answers. So that they can organize their theory...and it kept circulate."

From seeing themselves as knowledge receivers, to seeing themselves as knowledge creators

To build and create knowledge, one must not only understand the knowledge-creation process, but must also believe in their capability to create knowledge. Interviews showed that students started to see themselves as knowledge creators, rather than mere knowledge receivers, after their experience with knowledge building, as one student FYL reflected, "I used to think that knowledge only existed in the textbook, actually, we have lots of problems around us that have not been explored yet." Another student HBY said, "I also thought knowledge only existed in books. [Now I understand that] many people can create knowledge. And we ourselves can also create knowledge..." In addition to believing in their capacity to create knowledge, they also started to see knowledge creation as a socially constructed process. For example, student CHEN said

...Now I think that knowledge can not only be obtained from the book, but also generated by our discussion....it is not only limited to the Internet, books... I now think we ourselves can also discover knowledge...(Can you explain more about 'discover knowledge')...discuss with classmates. In Knowledge Forum, when someone asked questions, we would try to answer the question, while we were thinking and solving the problem, we learned new things....you will rely on some of the material on internet, and incorporate them into your own thinking, and generate new knowledge.

This excerpt showed that CHEN used to think knowledge could only be obtained from books, but came to see himself as able to generate knowledge. He also started to think that knowledge was generated by questions, and was socially constructed. He even mentioned how students could make constructive use of authoritative information from the Internet to help them construct knowledge.

Discussion and conclusions

The study investigated how epistemic and conceptual growth could take place in the designed knowledgebuilding environment. Discourse and correlation analysis indicated that students' high level problem centred uptake and theory building moves were related to post-test epistemic and conceptual scores. Analysis of classroom dynamics showed both students' inquiry in the classroom (problem-generation, theory revision, design experiment to test KF ideas) and how epistemic reflections scaffolded by epistemic inquiry, discourse, and modeling have facilitated students' change of epistemic and conceptual understanding. The study showed that it is not adequate just to have students engage in inquiry tasks and forum writing; they need to reflect on their inquiry and we scaffold them to reflect on their own inquiry in light of scientists work. Interviews further showed the impact of the designed environment on students' epistemic understanding, and how students have changed from viewing science as concrete activities to theory building process, and how they started to see themselves as knowledge creator and to appreciate the role of collective theory building in knowledge creation.

This epistemic-enriched knowledge-building design is very different from the traditional inquiry-based approach, in which science is portrayed as a series of observation and experimentation, and which neglects the role of ideas in inquiry. The traditional simple inquiry, as Chinn and Malhotra (2002) put it, assumes an epistemology *opposed* to the epistemology of authentic science. Students' interpretation of these "artificial" inquiry tasks may affect how they understand the nature of knowledge and science. For example, if students merely do experiments without knowing that the purpose of experimentation is to test ideas, they may not understand the role of ideas in science; similarly, if students merely make posts on computer forums, or argue claims without attempt to improve them, they may not understand that ideas and theories are socially constructed that can be improved through online discourse. Accordingly, one possible explanation for the changes in epistemic understanding among students might be that underneath knowledge building is an

epistemology that is similar to that of the authentic scientific inquiry, and students' inquiry and reflection is a process of internalizing experts' epistemology, and therefore a process of improving their own epistemology.

This study has shown the possibility of changing students' understanding of the nature of science through a computer-supported knowledge building design. Our findings are consistent with the postulation that, if students are to understand certain aspects of the nature of science, they must experience those aspects and make metacognitive reflections thereon (Carey et al., 1989). This study also suggested that the kind of epistemic discourse that facilitates connections between scientific inquiry and their own knowledge building inquiry might be helpful for epistemic growth. Knowledge building theory (Scardamalia & Bereiter, 2006) postulates that members add value to knowledge production, similar to scientific communities. This design might make this more explicit with students working as little scientists; engaging in theory building; and reflecting on such processes as scientists and knowledge builders. The study has also identified the need to investigate further how to embed epistemic features, such as the *collective, ever-deepening*, and *progressive* nature of knowledge, into CSCL pedagogy to improve epistemic cognition. Future study can be conducted to further explore the role of epistemic discourse and reflection in students' epistemic change process.

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