

A Theory of Group Cognition in CSCL

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Abstract. The digital age of computer support has transformed human cognition. Although thinking always had social origins in the small-group interaction of family units, tribes, work teams and friendships, cognition is now enmeshed in networks of social media, technological infrastructure, online knowledge sources, global production. Computer-supported collaborative learning (CSCL) stands at the crossroads of this historic transformation. It explores how collaborative learning by small groups can become a foundational form of knowledge building—including for the individual group members and for the society in which the groups live. CSCL research also provides a laboratory for studying the nature of collective intelligence or group cognition. This introductory Investigation presents a paradigmatic CSCL setting and highlights the role of group practices as vehicles for collaborative learning. It addresses the dual questions of how intersubjectivity is possible and what the preconditions are for establishing, supporting and maintaining intersubjectivity—providing central pillars of a theory of group cognition and suggesting implications for educational practice. It then delves into the structure of collaborative discourse, analyzing data from exemplary CSCL sessions. The analysis of interactional structure points to a multilayered structure, in which individual, small-group and cultural cognition are intertwined.

Keywords. CSCL theory, group practice, paradigm example, social practices, co-experienced world, intersubjectivity, discourse structure, multi-layered analysis.

A Theory of Extended Cognition

The notion of group cognition proposes that human thinking and learning is at root interactional; the origin, influence and effect of human cognition extend essentially beyond the skull. We acquire our ability to think and to learn by adopting practices that arise within small-group interactions, such as in our family, work teams or collegial circles. Our thinking is responsive to and conditioned by our embeddedness in a physical, interpersonal and cultural environment—particularly the immediate discourse or action context.

Group cognition theory poses an alternative to psychological theories of mental phenomena in individual minds as well as to sociological theories of societal structures existing independently of the

people who inhabit those structures. According to group cognition theory, thinking and learning take place in the interactions among people and across the small groups of interacting individuals.

The theory of group cognition emerged from study of student discourse in CSCL settings. It is aligned with the writings of Vygotsky, Lave, Bereiter, Koschmann, Engeström and Hutchins as well as with socio-cultural, distributed-cognition and embodied-cognition approaches generally. However, it maintains a systematic focus on the small-group unit of analysis, which others often lose to a psychological or sociological priority for the individual or society. It is also in keeping with 21st century post-cognitive philosophy, such as that of Marx, Heidegger and Wittgenstein—who critique mentalism and individualism.

Theoretical Investigations of Group Cognition

The theory emerged in the writing of *Group Cognition* (Stahl, 2006, MIT Press). Aspects of the VMT research project and technology were developed and described in *Studying Virtual Math Teams* (Stahl, 2009, Springer). Various perspectives on the research were extended and explicated in *Translating Euclid* (Stahl, 2013, Morgan & Claypool). A detailed longitudinal study of a team of students engaged in successful collaborative learning of dynamic geometry was analyzed and presented in *Constructing Dynamic Triangles Together* (Stahl, 2016, Cambridge). The theory of group cognition has strong implications for the methodology of the learning sciences and for educational practice, as well as for CSCL technology design and design-based educational research.

These themes are all taken up in the Investigations of Part III of this volume:

- Investigation 15. *A Paradigmatic Unit of Analysis*. A paradigm example of CSCL is presented: The Virtual Math Teams (VMT) Project was designed to develop a technology platform and pedagogy for sustaining collaborative learning within small groups of students discussing mathematics and solving problems together. The VMT online environment was instrumented to collect data of student interactions. Using this example, it is argued that CSCL can offer a distinctive and timely new paradigm of educational research, focused on the small-group unit of analysis.
- Investigation 16. *Group Practices*. Using multiple examples from VMT sessions, it is suggested that the adoption of shared practices by student teams is central to the collaborative learning that takes place in these groups. Group practices may or may not be derived from or related to either individual or cultural practices (such as rules from school mathematics), but they are adopted by the group in its collaborative work. Effective curriculum can be designed to encourage adoption of strategic group practices that contribute to skilled behavior in the contemporary world. Collaborative learning can be defined, designed, supported, fostered and evaluated in terms of the adoption of specific relevant sets of group practices.
- Investigation 17. *Co-experiencing a Shared World*. CSCL raises the question of how multiple individuals can “share” practices, learning or thinking as proposed by the concept of group cognition. In this Investigation, examples of discourse data from several VMT sessions show how the members of an effective group participate together within a shared world. This experience of interacting within a co-experienced world provides a basis for their shared understanding. There are many ways that group members negotiate and sustain joint attention to objects, experience them together, negotiate their shared understanding and repair potential misunderstandings.
- Investigation 18. *From Intersubjectivity to Group Cognition*. The question of how people can share understandings and understand each other is a philosophical issue. It has been discussed by a series of philosophers and social scientists. This Investigation tracks an evolving analysis of this discussion through about a dozen stages, culminating in the theory of group cognition.

- Investigation 19. *The Constitution of Group Cognition*. The analysis of three VMT examples of interaction shows typical mechanisms used to achieve intersubjectivity. In particular, groups engage in extended sequences of dialogical responses to each other, building longer argumentation structures, such as informal derivations of mathematical conclusions. They remain involved in persistent co-attention to shared objects of interest. By co-experiencing these micro-worlds, they establish and maintain shared understanding.
- Investigation 20. *Theories of Shared Understanding*. The usual view on how shared understanding among multiple minds is possible involves the notion of “common ground.” This Investigation considers several prevalent, competing theories, including that of common ground. They are subjected to analysis in terms of evidence of how small online groups of students develop, check and maintain shared understanding, thereby constituting group cognition.
- Investigation 21. *Academically Productive Interaction*. The recent pedagogical theory of “academically productive discourse” or “accountable talk” is primarily oriented toward individual cognition. Accordingly, it adopts the approach of cognitive convergence, guiding individual students to converge their own understandings with the understandings of other students, the teacher or the community. In the alternative paradigm of group cognition, one tries to guide groups of students to maintain and build on their co-presence and intersubjective shared understanding to articulate their largely tacit shared group understanding.
- Investigation 22. *Supporting Group Cognition with a Cognitive Tool*. CSCL is motivated by the potential to design technologies to support collaborative learning. In this Investigation, the use of a pointing tool in the VMT environment is explored. The tool permits a student to point with a graphical connecting line from a current chat-text posting to a previous post or to an object or area on the shared whiteboard. This supports deixis, the ability to direct the attention of others to an object of interest. Pointing is a ubiquitous means for supporting joint attention and this tool provides an effective digital analog of physical pointing.
- Investigation 23. *Sustaining Interaction in a CSCL Environment*. Interaction in groups takes place through sequences of actions, such as text-chat postings, spoken utterances, drawing movements or bodily gestures. These can often be analyzed in terms of pairs of actions, such as the posing of a question followed by the offering of an answer. Here, the question elicits an answer, setting the stage on which a respondent is encouraged to provide an answer. In turn, the answer confirms by its responsiveness that the preceding action was taken as a question and completes the meaningful question/answer interaction. While a question encourages interaction to continue with an answer, the answer could end the interaction. To sustain interaction, such response pairs must themselves be combined in larger structures.
- Investigation 24. *Viewing Learning and Thinking in Groups*. This Investigation proposes a systematic approach to revealing larger structures in CSCL settings. It provides a view of group interactions such as those analyzed in the VMT Project as hierarchically structured, with events (like VMT Spring Fests), composed of sessions, covering multiple themes, built out of sequences of discourse moves, consisting of adjacency pairs, linking utterances, including references. This hierarchy provides a framework for analyzing student interaction with a view toward structurally understanding group cognition.
- Investigation 25. *Structuring Problem Solving*. In this Investigation, an extended interaction in VMT is analyzed in some detail to show how a sequence of discourse moves is built up out of adjacency pairs, eventually carrying out a mathematical derivation by a small group. It is common to consider mathematical derivation the work of an individual thinker; however, here we see a group construct a result that no one of the individual students involved would have been able to do. The analysis of the derivation must be conducted at the unit of analysis of the group interaction.

This set of discussions raises several central problematics of a theory of group cognition. These are particularly germane to CSCL, which focuses on small groups of students communicating over networked computers. The theory of group cognition claims that “groups can think.” This is a new idea, reflecting that our era of digital technology has changed the nature of knowing, understanding, thinking. Now there can be various collective levels of interacting groups, networks or communities who interact across computer-based media. For researchers, the collective basis of cognition raises many issues, necessitating a rethinking of how to generate, collect and analyze data for studying collaborative learning and group cognition. The following aspects of these issues will be discussed in the remainder of this Investigation:

- a. The nature of intersubjectivity, including the conditions necessary to establish and maintain it. Investigations 15, 16 and 17 take different approaches to conceptualizing the collective group and understanding the ways intersubjectivity can be established within the groups. See “Conceptualizing the Intersubjective Group” below.
- b. A methodology for studying and understanding intersubjectivity. Investigations 18 and 19 trace theories of intersubjectivity and common ground. A key to the analysis of intersubjectivity is derived from ethnomethodologically informed conversation analysis, which developed the analysis of adjacency pairs in discourse. The theory of group cognition draws upon this for its analysis of the response structure of group interaction. See “Ethnomethodologically Informed” below.
- c. The relationship of group cognition to artifacts, including tools to support collaboration. Investigations 20, 21 and 22 consider ways to foster collaborative learning through pedagogical and technological systems of support. This is critical for effective CSCL learning, which is necessarily mediated by technological artifacts (e.g., communication media and/or subject-domain representations). We need to consider how such mediation takes place. See “Artifacts and Collective Minds” below.
- d. The interrelationships among multiple levels of description, such as individual, small group and community. Investigations 23, 24 and 25 are concerned with the structure of interaction at the small-group unit of analysis. It is important to consider this within the larger context of the relation of the small-group level to the individual and social layers of thinking and learning. See “Traversing Planes of Learning” below.

These thematic areas are discussed here based on editorial introductions to issues of *ijCSCL* that emphasized these areas (Stahl 2012a; 2012b; 2012c; 2013; 2015), and some of the papers published in those issues.

Conceptualizing the Intersubjective Group

Intersubjectivity may be considered the defining characteristic of CSCL [Investigation 15]. *Intersubjectivity* is a concept that indicates *shared understanding* among people [Investigation 18]. This “sharing” is not a matter of individuals having similar understandings, but of them participating productively in a joint meaning-making discourse within a communal world. A group has achieved intersubjectivity if the members of the group interact well enough to pursue the group’s aims. Intersubjectivity must be built up gradually through interaction and repaired frequently. CSCL research should explore the conditions and processes that are conducive to the establishment and maintenance of intersubjectivity among groups of learners. CSCL pedagogies should be structured to promote the intersubjectively shared understanding that makes collaborative learning possible. CSCL technologies should be designed to support intersubjectivity by providing media of communication and scaffolds for meaning making within specific domains of learning.

When CSCL theories discuss “groups,” they are not referring to arbitrary gatherings of multiple learners, but to functional groups that have achieved a degree of intersubjectivity. The concept of collaborative learning in CSCL does not refer to a sum of individual learning that takes place among a group’s members, but to the increase in inter-subjective understanding or collaborative knowledge building within the group that results from joint meaning making in a shared context. It involves the understanding expressed in the group discourse and the knowledge encapsulated in group products, such as texts or artifacts. The group’s understanding may differ from what any individual member might say, write or think when not interacting within the group.

This focus on the intersubjective group differentiates CSCL from other approaches to the study of human learning and educational instruction. It implies a research paradigm that prioritizes the group unit of analysis and studies groups that have achieved intersubjectivity. Analyzing an utterance (or chat posting) as part of a group interaction involves seeing how its meaning is constructed sequentially through its response to previous actions and elicitation of future behavior by other group members. The meaning of the utterance is inherent in the working of that utterance within the shared world of the group, not to be explained in terms of some purported individual mental thoughts accompanying the utterance. As in Ryle’s (1968) thick description of a wink, the meaning of an utterance (or wink) is expressed by the utterance (wink) itself as an interactional action, not by assumed additional mental intentions of the speaker (winker).

Despite the centrality of the notion of intersubjectivity to CSCL, this concept has not often been explicitly discussed in the CSCL literature. Newcomers to CSCL therefore have difficulty determining the boundaries of the field. They may assume that CSCL is the same as traditional educational psychology or instructional design, except that it involves small groups and online technology. However, the importance of analyzing intersubjectivity at the group unit of analysis has become increasingly clear to many established CSCL practitioners. For instance, the *ijCSCL* Mission Statement now specifies that the journal “features empirically grounded studies and descriptive analyses of interaction in groups, which investigate the emergence, development and use of practices, processes and mechanisms of collaborative learning.” The central research questions are no longer what experimental conditions produce the most valued learning experiences or outcomes at the individual unit, but how intersubjective meaning making and understanding is established, maintained and increased within the *interaction in groups*, by social practices, small-group processes and interactional mechanisms analyzed at the group unit.

The shift of research from assessing individual student outcomes to analyzing group-level phenomena has been slow coming and is still difficult to implement consistently. In the late 1900s, educational researchers like Johnson and Johnson (1999) or Slavin (1980) explored the effects of group interaction on learning outcomes of individual students; this was called *cooperative* learning. The focus was on individual cognition, but in cases where the individual was somehow influenced by being in a group. With the advent of CSCL, interest changed to the group processes that could be supported with networked-computer technologies. In their report on the evolution of research on *collaborative* learning, Dillenbourg, Baker, Blaye and O'Malley (1996) noted that new methods were now necessary to study group phenomena. Although Koschmann (1996) proposed that this involved a paradigm shift, it has not been widely recognized what a radical change in perspective and methodology this shift to the group level implied.

Subsequently, Koschmann (2002) defined CSCL in terms of “joint meaning making.” The centrality of intersubjective meaning making to the concerns of CSCL as a research field have been stressed programmatically in scattered proposals and examples, for instance in Investigations 4, 5, 12. Multiple attempts to define new methods corresponding to this agenda of group-level analysis were also proposed, as in Investigations 6, 7, 8, 9, 10 and 11 as well as several other *ijCSCL* articles.

After 20 years, CSCL researchers are just beginning to work out group-level conceptualizations, such as group cognition, group knowledge construction, group agency, group engagement, group

metacognition, group practices and so on. Some researchers now see CSCL as pursuing a post-cognitive paradigm distinguished from the cognitivism of the learning sciences [Investigation 15].

Co-Operative Action

Goodwin (2013; 2018) has recently developed an analysis of the essential intersubjectivity of human cognition within a post-cognitive perspective, grounded in a number of ethnomethodologically informed analyses of interactional data, including family members conversing, children playing and arguing, anthropologists or chemists learning analytic skills, and videotaped evidence being presented in a courtroom. As diverse as these settings are, they all involve small groups of people in face-to-face interaction. In this volume, we will adopt much of Goodwin's perspective, but apply it within computer-mediated scenarios.

Like group cognition theory, Goodwin's post-cognitive approach is not focused on psychological states as making human cooperation possible, but rather on "public social practices that human beings pervasively use to construct in concert with each other the actions that make possible, and sustain, their activities and communities" (2018, p.7). In place of a model of the speaker that takes as its point of focus mental phenomena within the individual actor, Goodwin identifies how people constitute their participation in discourse through their ability to "engage in appropriate but differentiated ways in a field of interactively sustained action constituted through the public organization of language use" (2013, p.15). These ways correspond to what Investigation 16 calls group practices.

The accumulation of group practices is central to the organization and evolution of human culture, knowledge and social life (Investigations 7, 16); the adoption and use of these practices by small groups pervades social life. Goodman, citing the philosopher and semiotician Pierce, highlights in particular the central importance of diagrammatic reasoning in human thought, noting that geometry provides a perspicuous example. The historic role of Euclidean geometry as a training ground for cognitive practices which integrate visual, logical, gestural and representational practices was a motivation for the VMT Project's focus on collaborative dynamic geometry as a subject domain.

Goodman provides an analysis of co-operative action that can usefully be applied to the study of VMT interaction data. The term "co-operative" is chosen because people typically perform specific operations in coordination with each other. Or instance, a speaker will decompose materials provided by another speaker and then reuse them with transformations. Goodman takes this process of decomposition and reuse of resources to be a very general and unique characteristic of human cognition. Mankind innovates by analyzing (taking apart) ideas and tools accessible in the social world and recombining them in transformed ways. In particular, our speech is generated by decomposing, and reusing with transformation the resources made available by the preceding speech of others. So their language becomes ours, and ours is a form of theirs: "We inhabit each other's actions" (Goodman, 2018, p.1).

The operations of decomposition and transformation take place in multi-dimensional settings, resulting in what Goodman calls environmentally coupled gestures. These require for their understanding not only a gesturing hand, but also the environment being pointed at and co-occurring language that formulates what is to be seen there in a specific way. For instance, anthropologists train their students to see and discuss subtle shades of ground at an excavation by pointing to color charts and using technical terminology. Similarly, students in VMT learn to construct challenging geometric dependencies by highlighting or making salient specific graphical elements on the computer screen and chatting about them using geometric terminology. This kind of co-operative action or group cognition is a fundamental way in which groups accumulate group practices, group members become more skilled and the community builds knowledge. As Goodman puts it,

The accumulation and differentiation through time within local co-operative transformation zones of dense substrates create a multiplicity of settings for action. Each of these must be

inhabited by competent members who have mastered the culturally specific practices required to perform the activities that animate the lifeworld of a particular community. Through the progressive development of, and apprenticeship within, diverse epistemic ecologies, communities invest their members with the resources required to understand each other in just the ways that make possible the accomplishment of ongoing, situated action. (2013, p.21)

Not only does this process make possible new professions and realms of knowledge, it recursively forms the basis of intersubjectivity, required for all mutual understanding.

Translating Goodman's view of co-operative action to the concrete situation of the VMT paradigmatic case of CSCL, we can observe student teams decomposing and transforming each other's contributions. Trausan-Matu (Trausan-Matu, Dascalu & Rebedea, 2014; Trausan-Matu & Rebedea, 2009) has analyzed VMT transcripts using Bakhtin's notion of polyphony, showing how students build on each other's word use to inhabit an inextricably interwoven shared world.

Perhaps even more striking would be an analysis of how a team working on geometry decomposes and transforms each other's construction efforts. Although it would be tricky to present a detailed study of this concisely, the data is now available in the recordings of the Cereal Team in their Winter Fest 2013 interaction, especially Session 6 (Stahl, 2015). Here, the three students took turns extensively exploring how to construct points, lines, circles, triangles, squares and polygons with specific dependencies. There was lots of trial and error, but an adequate analysis would show that it was by no means random efforts. Each student closely observed the deadends that the others ran into. They decomposed the false starts by erasing the shared workspace and then reconstructing the effort with key transformations, which eventually led to success. The successes were immediately recognized by the whole group and adopted into the future work of the group and of its members. This resulted in a shared understanding of their intersubjective meaning making in the shared VMT world.

The Conditions of the Possibility of Intersubjectivity

Several articles in the 2015 10(3) issue of *ijCSCL* focused on intersubjectivity; they illustrate and further develop a group-level focus of CSCL research. For instance, the first article provides a discussion of Habermas' philosophy as it relates to CSCL issues and introduces to the CSCL audience the work of the contemporary author who has written the most on the concept of *intersubjectivity*. Then, three papers analyze the intersubjectivity of small groups of students in different ways. One looks at how *groups learn how to learn together* with support from specific CSCL tools. A second transforms the concept of engagement to the group unit of analysis as collaborative *group engagement*. The final one makes a parallel move for *formative feedback and metadiscourse*, applying them at the group level. Together, they offer stimulating glimpses of CSCL theory, technology, meta-learning and analysis focused on the group as agent.

In his introduction of Habermas' philosophy of communicative action to the CSCL community, Hammond (2015) translates from Habermas' application of this theory in the public sphere of traditional media to the online world of CSCL. For Hammond, Habermas is relevant because he brings a fresh, well-considered and critical perspective to the discussion of joint knowledge building. In particular, Habermas' writings provide a framework for judging the evidence we bring to the analysis of collaborative learning as well as for valuing the evidence that our student subjects provide in their argumentation. Habermas defines the conditions necessary for the establishment of intersubjectivity, such as the inherent assumption of an ideal speech situation underlying communicative action. What Kant's *Critique of Pure Reason* did for the individual mind, articulating the conditions of the possibility of human knowledge, Habermas translated to the group level, explicating fundamental discourse conditions necessary for intersubjective meaning making in social collectivities.

Consider a student chat, a discussion forum or a medium like Wikipedia. How should we judge the quality of the knowledge building that takes place there? Moreover, how should one judge the quality of researchers' analysis of that knowledge building? Habermas provides a standard for judgment that is grounded in the nature of human discourse. He argues that effective communication would be impossible without the underlying postulation of an ideal speech situation—even if this ideal is never in fact fully achievable (Habermas, 1981/1984). The act of communicating with the aim of establishing intersubjectivity, making shared meaning and building knowledge together assumes that there is no other force of persuasion at work than that of the better argument and no other motivation than the cooperative search for truth. Enlightened discourse is only possible under the assumption of this goal. Of course, there always are other forces and motivations present. But the character of the ideal speech situation that underlies collaborative dialog provides a basis for critiquing those systematically distorting forces. For instance, if knowledge building assumes that no one can impose his or her views through force rather than through supported reasoning, then appeals to authority or intimidation can be soundly censured.

Habermas' theory is, additionally, more complex and nuanced. A major contribution of his work was to distinguish realms with different criteria within the public sphere (Habermas, 1967/1971). There is, as Hammond puts it, the objective world (of nature and labor), the social world (of institutions and interaction) and the subjective world (of personal experience). Each has very different criteria of validity. The objective world follows the laws of physics and involves human mastery over nature through technical, goal-oriented, instrumental calculation; the social world, in contrast, involves normative rules reached through negotiation; while the subjective world is a matter of one's self-narrative.

Consider the research task of analyzing an online team of students collaborating on a geometry construction. Certainly, this involves comparing the team's work with mathematical knowledge developed in the objective world of mathematical relationships. However, it also involves tracking the development of the team's adoption and mastery of its own group practices of collaborating and of working on geometry in the team's intersubjective world. Furthermore, it may be possible to assess individual learning by team members as a personal-world spin-off of their teamwork. Each of these dimensions has quite different methodological criteria. Seeing how each is accomplished with the mediation of specific CSCL pedagogical approaches or CSCL technological tools can feed into design-based research for improving support for collaborative knowledge building.

Habermas' distinction between the objective, social and subjective realms gives him leverage for his critiques of modernism and other popular philosophies, extending the critical social theory of the Frankfurt School. As cited by Hammond, Habermas' concern with mutual recognition led him to criticize classical liberalism for reducing ethical liberty to a "possessive-individualist reading of subjective rights, misunderstood in instrumentalist terms." There are many analogous examples in the CSCL literature, where social phenomena are inappropriately reduced either to individual subjective criteria or to instrumental objective criteria. Hammond suggests that a focus on intersubjectivity could provide a corrective in such cases and open up new perspectives for design and research. It is important to distinguish different levels of analysis carefully and to apply the appropriate evaluative criteria or analytic methods to each.

Intersubjective Learning to Learn

Teaching students to learn how to learn or to develop "thinking skills" has long been considered important—particularly in the information age, where knowledge evolves rapidly (e.g., Investigation 13; Wegerif, 2006). In their research report in the same *10(2) ijCSCL* issue, Schwarz, de Groot, Mavrikis and Dragon (2015) extend this goal to the group level with their construct of learning-to-learn-together. A core component of this approach is supporting groups of students to engage in argumentation as a form of intersubjective meaning making. Schwarz and colleagues situate computer support for argumentation in an innovative dual-interaction space.

The authors take a design-based-research approach to developing a software environment, curricular tasks and teacher roles for supporting learning-to-learn-together. They hypothesize that mutual engagement, collective reflection and peer assessment may be three critical group processes to encourage and to investigate. To explore these, they design a prototype with two primary components: a construction space and an argumentation space. The construction space includes a selection of domain-specific modeling applications to support student inquiry in specific topics of mathematics or science. This provides a mutually visible “joint problem space” for collective reflection by the group on the progress of its inquiry. The software creates a shared world for mutual engagement, as opposed to individuals trying to solve a challenging problem on their own. As one group member performs an action in the space, the others assess that action in the argumentation space, either affirming it or questioning it. This prompts the students to build on each other’s actions, producing a joint accomplishment.

In some dual-interaction systems, like VMT, a text-chat feature accompanies an online construction space. This provides the possibility of engaged discourse, group reflection and peer assessment when group members are not situated face-to-face. However, the described argumentation system goes beyond this with a sophisticated planning/reflection tool. Even if the students are sitting together around a shared computer, this tool prompts, guides and supports team efforts at planning steps for the group to take (collective agency) and it facilitates team reflection on the current state (collective responsibility). While the software mainly displays advice and ideas from the teacher or from individual students, its persistent visibility and its manipulable structure allow it to influence group agency and meta-learning. The potential power of this approach seems to come from the integration of the support for argumentation and reflection by the group with the inquiry activity itself in the shared inquiry environment. As always in CSCL, success also depends on a culture of collaboration: appropriate motivations/rewards, careful training in collaboration and subtle mentoring. The emphasis of the pedagogy and the support throughout is on the group as meta-learner.

Intersubjective Engagement

In the next presentation of the *10(2)* issue, Sinha, Rogat, Adams-Wiggins and Hmelo-Silver (2015) provide a multi-faceted conceptualization and operationalization of intersubjectivity based on aspects of what they term “group engagement.” Using this approach, they provide a clear illustration of a team of students that does not form an intersubjective group contrasted by one that does. The construct of group engagement developed in this paper allows the authors to identify this contrast and to analyze it using both quantitative and qualitative methods. The quantitative approach includes statistical correlations based on ratings of several aspects of group engagement, measured in five-minute intervals. The qualitative approach involves thick descriptions of illustrative excerpts of group discourse. The descriptions relate the interactions within the groups to their work (or lack thereof) of meaning making in establishing the engagement of the group as a whole in its problem-solving task.

A major achievement of the paper is to shift the analysis of engagement—which is increasingly popular in CSCL—from the psychological individual to the intersubjective group unit of analysis. The authors are explicit about this. Their observational protocol is designed to situate engagement within the collaborative group, its joint problem and its shared situation. For instance, the dimension of social engagement reflects group cohesion, or evidence that the task is conceptualized as a team effort, rather than as an individual activity. The contrast of one group’s use of the subject “we” versus the other’s use of “I” reflects in the details of the discourse the distinction documented in the ratings—showing that the distinction is actually one made by the group.

The paper is an impressive response to the cited prior research on engagement. According to the literature review, earlier studies generally operationalized engagement as consisting of a single dimension, as a stable state and as a characteristic of the individual learner. In addition, the cited work decontextualized engagement from concomitant conceptual and disciplinary tasks. By contrast, this study

proposes a differentiated, evolving, multi-faceted and group-based model of engagement and applies this model to explore an insightful example from actual classroom practice. The paper's mixed-methods analysis reflects a careful attention to the unit of analysis, operationalizing engagement at the group level. Thereby, it adds in a rich way to our conceptualization of intersubjective meaning making.

Intersubjective Metadiscourse

Like the preceding paper, the one by Resendes et al. (2015) also uses mixed methods, with both quantitative and qualitative analysis. While collecting data at both the individual and group units of analysis, its focus is also at the group unit. In fact, it goes a step further than the previous paper and most other CSCL reports by capturing the outcomes at the group level. Here, because the main data source is a Knowledge Forum database, the group product of shared notes responding to each other within the group is the most important object for examination in response to the primary research question. Thereby, the correlation of the experimental condition with resultant collaborative learning or knowledge building can be conducted at the group level.

The social-network analysis of the Knowledge Forum data shows the effect of experimental feedback tools on the group process and the degree of intersubjectivity established by each group. The paper's analysis strikingly indicates that in the control condition most students are not strongly connected to other students, whereas in the experimental condition everyone is strongly connected to everyone else. Because the social-network connections here represent sharing of vocabulary terms—such as those displayed in the experimental condition's feedback tool—this means that there is a higher degree of intersubjective, shared understanding in the experimental groups. Shared understanding at the group unit of analysis is not dependent upon individuals' cognitive states, internal representations or personal understandings, but is visibly displayed in the team's unproblematic use of shared language.

We are shown further evidence of increased group metadiscourse through the analysis of group discussion in a number of propitious interaction excerpts. While these demonstrate the experimental group's comprehension of the visualizations of their group discourse (displays of its use of domain vocabulary and of Knowledge Forum epistemic markers), the primary metadiscourse moves (prompting the group to plan, question, analyze, explain) were made by the teacher, rather than by the student group. The experimental intervention at the group level led to productive metadiscourse, but this was not at all independent of the teacher. Thus, the study merely indicates a potential for the design of formative assessment visualizations that represent group-level behaviors and that support group metadiscourse. It does not demonstrate that the implemented tools led to student metadiscourse on their own. The students may need more experience with this approach or more maturity to take on this form of agency within the student group. Nevertheless, the paper offers stimulating design suggestions: group-level formative feedback can represent group vocabulary; support the group to evaluate its own progress; give feedback on secondary processes (like vocabulary building, rather than directly on learning or task accomplishment); suggest positive steps (rather than just identify deficiencies); facilitate self-assessment by the group; and guide individual students to become more effective group members.

Together, the papers in issue 10(3) of *ijCSCL* suggest the centrality of intersubjectivity to a theory of CSCL and provide inspiring examples of how to explore and articulate aspects of our conceptualization of group intersubjectivity.

Ethnomethodologically Informed

The research field of CSCL is ethnomethodologically informed, or at least ethnomethodologically influenced. This has not always been the case, although there is a logic to this growing tendency.

Ethnomethodology (EM) is an approach to conducting research in the human sciences founded by Harold Garfinkel and largely defined by his *Studies in Ethnomethodology* (Garfinkel, 1967; Garfinkel & Rawls, 2012). EM addresses the “methods” that members within a given linguistic community use to establish and maintain intersubjective understanding. Since CSCL can be characterized as being focused on joint meaning making, the analysis of prevalent meaning-making methods seems particularly relevant to the methodological quandaries of CSCL research.

Ethnomethodology has been slow to catch on in CSCL, in contrast to its role in allied fields like CSCW, where it seems to be a dominant research paradigm. There are a number of theoretical and historical reasons for this. For instance, as discussed below, practitioners of EM eschew research questions and theoretical framings because these could obscure the meaning-making perspective of the people whose interactions are under investigation. This injunction against guiding theory makes it difficult to integrate EM studies into the educational and design agendas of CSCL investigators. In addition, the case-study approach of EM to analyzing naturally occurring events is at odds with the traditional emphasis in educational and psychological research on controlled experiments and statistical generalizations. CSCW is based more in social sciences, in contrast to the psychology foundations of much CSCL.

On the other hand, there are strong arguments for viewing the ethnomethodological approach as especially appropriate for analyzing computer-supported collaborative learning. In particular, a major stream of research within EM has been conversation analysis. This is the analysis of talk-in-interaction, as pioneered by Sacks (1965/1995) and other colleagues of Garfinkel. An early finding of conversation analysis was the system of turn taking in face-to-face informal conversation. While this system does not apply directly to such CSCL interactions as online text chat about an academic topic (Zemel & Çakir, 2009), the underlying techniques of sequential analysis (systematized by Schegloff, 2007) seem highly applicable to the analysis of meaning making in CSCL settings. Such sequential analysis explicates the evidence embodied in instances of discourse that reveal meaning-making processes taking place in small groups [Investigation 25]. It looks at the semantic, syntactic and pragmatic details of how utterances respond to each other and elicit new responses in the flow of group cognition.

The Historical Traditions of CSCL Research

To a large extent, early CSCL investigators turned from inspirations in computer science and artificial intelligence to the fields of educational psychology and sociology to find methods of studying the effects of using CSCL systems in classrooms or in laboratories. The theories and research paradigms that they brought in from these established fields focused on either the individual student or the larger society as the unit of analysis. Educational theory operationalizes learning as a hidden change in mental state of student knowledge from before an intervention to after, as measured indirectly by pre- and post-tests of individual students. At the other extreme, social science approaches hypothesized societal forces that could not be observed directly, but could be inferred and measured by controlled experiments using statistically significant numbers of randomly selected subjects.

Ethnomethodology—drawing on philosophical influences from phenomenology and reacting against functionalist approaches to sociology—takes a different tack, centered on what is made visible in the interactions between people. EM argues that one can observe the meaning-making processes at work by carefully studying the discourse between people; one does not have to make inferences about hidden changes in mental models or invisible social structures. Furthermore, EM studies can focus on the small-group unit of analysis, which seems most appropriate to analyzing collaborative learning. While other areas of education and of sociology may seem centrally concerned with individual or societal units of analysis and while collaborative learning may also involve processes and phenomena at those levels, the meaning making in contexts of joint activity which is definitive of CSCL takes place primarily at the small-group level, even if a complete understanding will need to tie all the levels together.

The ability to conduct microanalysis of interaction was historically made possible by recording technologies, which allowed utterances to be replayed and slowed down. Conversation analysis arose in the age of the tape recorder. That technology made it possible to hear exactly what was said and how it was articulated. It allowed the production of detailed transcripts, which represent intonation, pauses, emphasis, restarts and overlaps so that the mechanisms of verbal interaction could be studied. Subsequent development of video recording led to analysis of gesture, facial expression, gaze and bodily posture as important but generally unnoticed aspects of interpersonal interaction. For online communication typical of CSCL, computer logs and even the ability to replay synchronous interaction can provide adequate data sources necessary for the study of how students actually engage in computer-supported collaborative learning.

Applied to CSCL, the approach of EM implies that we can observe and report on the ability of given technologies and pedagogies to mediate collaborative interactions between students in concrete case studies. EM suggests ways to do this systematically, with intersubjective validity, and to generalize the findings. Insights from this can be used to critique the designs of interventions and to suggest redesign criteria. To make these claims about EM plausible, we will need to review some of the principles of EM.

The Theoretical Framing of CSCL Research

There is a prevailing notion that EM is atheoretical or even anti-theoretical, that it rejects all theorizing. Yet Garfinkel and Sacks (1970) were highly theoretical thinkers, influenced by philosophy, sociology and communication theory. In fact, EM represents a strong theoretical position about the nature of human reality and the possibilities of comprehending it. EM claims that human social behavior is structured by a large catalog of “member methods”—patterned ways of making intersubjective sense with other members of one’s linguistic community. Furthermore, these member methods are “accountable” in the sense that they provide an observable account of their own character. People’s actions are designed so that the meaning of the actions will be recognizable by others within the given discourse situation. This accountability is necessary for intersubjective understanding among members. But it has the secondary consequence that researchers can understand the methods as well (given certain conditions). The theory of EM thereby explains how EM is possible as a scientific enterprise.

The member methods of a linguistic community contribute significantly to the social order of activities within the community. The social structure is enacted in the very interactions of the members by virtue of their use of these methods; the accountability of the methods, as they are realized, reveals to the other participants (and potentially to researchers) evidences of what is being enacted. As Garfinkel put it, “any social setting [should] be viewed as self-organizing with respect to the intelligible character of its own appearances as either representations of or as evidences-of-a-social-order” (Garfinkel, 1967, p. 33). There is reflexivity at work between the meaning of an elemental interaction (e.g., an utterance/response pair) and the local context of the on-going discourse, in which the utterances are situated within a context whose significance they interpret in a continuously emergent way. The theory of EM is formulated in its concepts of member methods, accountability, reflexivity, etc.

The reason that EM is often considered to be atheoretical is that it systematically rejects the kind of theoretical framing that is associated with many other research approaches. For instance, in other paradigms an experiment and its analysis are motivated and structured by a theory or conceptualization of the phenomena to be studied. There may be a specific research question that the researchers have in mind. There may even be hypotheses about how the experiment will turn out based on preconceptions. While scientific researchers must remain open to their hypotheses being disproven by the evidence, the posing of research questions and hypotheses define a research perspective within which the evidence is pre-interpreted. For instance, CSCL discourse data might be coded according to a set of codes designed to make distinctions relevant to this perspective, experimental conditions will be structured to test these

distinctions and coders will be trained to categorize their data from this perspective—all before the students even interact or produce their utterances.

EM, in explicit contrast, wants to understand the data from the perspective of the participants in the study (e.g., students). Because the analysis of discourse is a human science, it must take into account what the discourse means for the speakers and audience. The participants are viewed as people engaged in meaning making, and EM researchers want to understand the meaning that the participants are making. EM researchers do not want to impose a perspective on the data analysis that is based on their own preconceived theories about the interaction. Rather, they want to engage in “thick description” (Ryle, 1949) of the discourse to explicate the meaning making that is taking place in the discourse and that is displayed in the accountability of how it is formulated. The fact that the discourse is accountably intersubjectively understandable allows the researcher to analyze the meaning that is implicit in the discourse as it sequentially unfolds.

This is the sense in which EM rejects theory: that it adopts the participant perspective on understanding the meaning in the data, rather than imposing a perspective based on a theoretical research framing. There has been considerable debate within CSCW about how EM analysis can be used to guide design of collaboration systems if it cannot be directed toward theoretical issues (e.g., see Crabtree, 2003). But the stricture against theory in EM is only against imposing an *a priori* analysis framework, not against drawing theoretical consequences from case studies. So one can, for instance, study the discourse of students embedded in a computer-supported interaction, and analyze the nature of the methods they use—which they enact, adapt or create—for achieving their collaborative tasks. The details of these methods can have design implications, such as addressing technical barriers that resulted in unnecessarily cumbersome behaviors. Thus, EM can contribute to the analysis phase of design-based research (DBR Collective, 2003), which is a widespread approach in CSCL to the design of effective collaboration technologies.

The Ubiquity of Methods

Ethnomethodology posits the existence of member methods pervading all of social life. EM research for the past fifty years has documented many such methods, for instance in informal conversation, in doctor-patient discussion, in mathematical proof, in criminal interviewing and in workplace communication. These methods are often sedimented in the traditional design of the tools we use and in the clichéd turns of speech within our vernacular. They constitute our myriad overlapping cultures.

Sacks (1965/1995) argued that the pervasiveness of member methods meant that one could profitably study almost any interaction and learn from it about the nature of social existence. He argued that the universal application of these methods was necessary if people were to understand each other. In the CSCL literature, one often talks about the establishment and maintenance of “common ground” (Clark & Brennan, 1991) as providing the foundation for intersubjective understanding. But, according to EM, it is not a matter of the participants having corresponding mental models of propositional knowledge; rather, intersubjectivity is founded on co-experiencing a world through using shared methods of communication [Investigation 17]. These methods provide “resources” for engaging in specific domains of the social world. According to the EM viewpoint, collaborative learning does not consist in the storing of propositional knowledge as mental contents in individual minds, but in the increasing ability to enact relevant resources or shared practices in interactions with others.

By looking carefully at interactions in CSCL settings, we can analyze the methods being applied. Because the acceptance of these methods is widespread within a culture, the results of a single case study can have quite general ramifications. Of course, to accept the implications of a single case study—or even a small catalog of case studies analyzing variations on a method—as valid and of general applicability, we need to ensure lack of bias or idiosyncrasy. This is usually addressed in EM by “data sessions” and other

mechanisms to involve multiple analysts (Jordan & Henderson, 1995). If discourse under analysis displays an account of itself, then a group of experienced analysts who share the relevant cultural understanding with the discourse participants should be able to reach a consensus about the meaning being created in the discourse. EM case-study publications frequently include very detailed transcripts of the relevant discourse excerpts to enable readers to confirm the analysis based on their own cultural understanding.

Group Practices

The identification of group practices—their adoption and use by groups—seems central to analyzing intersubjective meaning making and collaborative knowledge building in CSCL. Investigation 16 delineates a theory of group practices and proposes that CSCL methodology be centered on this.

Group practices are routinized behaviors that a group adopts and that ground intersubjectivity by providing shared understanding. They may mirror established social practices or member methods, such as procedures commonly used by experts in their work but as yet unknown to the students. The theory argues that the analysis of group practices can make visible the work of novices learning how to inquire in science, mathematics and other fields. These ubiquitous social practices are invisibly taken for granted by adults in their professional lives, but can be observed as they are brought into usage, and rigorously studied in adequate traces of online collaborative learning.

The analysis of the enactment of group practices by teams in CSCL contexts can systematically inform the design, testing and refinement of collaborative-learning software, curriculum, pedagogy and theory. Applied to the evaluation of trials of CSCL innovations, the analysis of how student teams adopt or fail to adopt desirable group practices contrasts with traditional pre/post comparisons that miss sequential interactional processes or that reduce group phenomena to either individual or social factors. Investigation 16 concludes by proposing that CSCL can be re-conceptualized as the directed design of technology to foster the adoption of targeted group practices by student teams.

The theory of group practices emerged from a longitudinal case study of a team learning the basics of dynamic geometry in eight hour-long VMT sessions. This data provides the prototypical example for the vision of CSCL being offered in the present volume. The interdisciplinary VMT research team at the Math Forum conducted a year of weekly data sessions on this data, resulting in a book-length analysis of the collaborative learning that took place (Stahl, 2016). A daylong workshop on the data was also held involving international researchers, and findings were discussed during visits by the author to European research labs.

During eight hours of chat and manipulation of geometric representations, the group employed countless social practices, most of which were intuitive, tacit and non-problematic for the students. However, over sixty group practices were also identified in the analysis as practices that had to be explicitly negotiated and adopted through group interaction processes.

The catalog of these adopted group practices agrees well with lists of social practices enumerated in the research literature. For instance, it includes online analogues of group practices (“member methods”) defined by face-to-face conversation analysis: sequential organization (response structure), turn taking, repair, opening and closing topics, indexicality, deixis, linguistic reference, and recipient design. Other group practices correspond to practices CSCL has previously investigated as providing foundations for intersubjectivity: joint problem spaces, shared understanding, persistent co-attention, representational practices, longer sequences and questioning. As observed in various VMT studies, practices in mathematics education include: mathematical discourse and technical terminology; pivotal moments in problem solving; and the integration of visual/graphical reasoning, numeric/symbolic expression, and deductive narrative. In addition, there were group practices that are necessary for constructing figures with specific dependencies in dynamic geometry.

It is likely that the VMT team picked up many group practices unproblematically, without having to go through an explicit negotiation process because the available resources—including the curriculum texts or classroom presentations before the online collaboration—guided smooth, tacit adoption of the practices. The curriculum, software environment and teacher guidance were based on careful study of what sorts of practices are involved in productive interaction related to collaborative dynamic geometry. This involved the researchers and the teachers developing personal experience with, for instance, constructing figures in Euclidean and dynamic geometry. They also read research reports about how students learn this domain. There are many physical practices involved in constructing different geometric elements on the computer screen and additional practices involved in dragging them to make sure they behave as desired. There are practices involving physical dexterity, computer manipulation, geometric relationships, communication, terminology, problem solving, explanation and so on. In a collaborative setting, these must often be shared as group practices.

The identification of group practices has substantial implications for the design and evaluation of CSCL software, curriculum, pedagogy and experimental intervention. According to the theory of instrumental genesis described in Investigations 6 and 7, it is not sufficient for a CSCL designer to have good ideas and honorable intentions; one must develop an initial prototype environment and try it out with groups of students. Based on observation of problems, the prototype must then be iteratively re-designed and refined. By observing breakdowns in group interaction and the gradual enactment of new group practices in response to the breakdowns, a designer can identify problem areas and constructive processes that need additional support. The analysis of group practices provides a systematic analytic method for driving CSCL design.

The analysis of adoption of group practices can be conducted either informally or rigorously. For instance, in browsing through the just completed online interaction of student groups one day, I noticed that one group had accomplished something impressive in their geometrical construction. However, they had not had time to reflect on what they had done in terms of negotiating new group practices or engaging in discourse about the “dependencies” that they had established in their construction. I had designed the tasks with the goal of deepening the students’ understanding of mathematical dependencies, so I wanted the students to spend more time interacting around their accomplishment. I emailed the teacher and suggested that she extend her groups’ work on this task the next day. Because I knew that I had designed the intervention with the intention of facilitating the adoption of group practices of discourse and construction related to the concept of dependency, I was oriented to scanning for this when replaying the student sessions. Informal analysis could drive design, altering the sequencing of topics and changing the wording for the next iteration of the course.

By contrast, to develop a deep understanding of what the student team accomplished in that session and how they built their knowledge interactively, I had to go over the data many times, in slow motion, and analyze it with other researchers experienced with mathematics learning. Eventually, we developed a nuanced sense of the development of the team’s group cognition. We saw how its shared understanding of mathematical concepts like dependency had developed significantly, but was still not robust. We catalogued the repertoire of group practices the team now shared, which provided it with an initial fluency in collaborative dynamic geometry, as intended by the design of the eight-session curriculum. We could then document the longitudinal development of mathematical cognition at the group level and observe the articulation of that newly acquired understanding by the team members’ discourse. We could specify the vaguely characterized cognitive evolution from concrete visual to abstract conceptual thinking in terms of the accumulation of adopted group practices, which we could observe and document.

Artifacts and Collective Minds

The age of simple objects like well-designed artifacts, minds confined inside of skulls, and cultures cloistered in the tacit background has been left in the fading past according to current socio-cultural theory [Investigation 3]. We are now enmeshed in dialectical processes of social enactment, whereby designed objects continue to evolve well after they enter into the structuring of our thought patterns [Investigation 6].

Biological human evolution has long since transformed itself into cultural evolution, proceeding at an exponential pace [Investigation 7]. Along the way, thought overcame the limits of individual minds to expand with the power of discourses, inscriptions, digital memories, computational devices, technological infrastructures, computer-supported group cognition, and virtual communities [Investigation 8]. Both human cognition and its mediation by technological artifacts morph from fixed nouns into process verbs [Investigation 10], like “cognizing mediating” (Stahl, 2012a)—where human cognition and technological media shape each other in ways we are just beginning to conceptualize.

The owl of Minerva flies only at night, according to Hegel’s (1807/1967) metaphor: theory—which is one’s time grasped in concepts—lags behind the continuous unfolding of practice. As today’s viral software successes rapidly outstrip our design theories, we must try to understand the ways in which new generations of users adopt and adapt their digital tools, thereby defining and redefining their conceptual, social and pragmatic ties to their worlds. Hegel theorized the dialectic between subject and object, proposing that the identity of the human subject is formed when a subject subjects an object to goal-oriented design (Stahl, 2006, p. 333f), creating an artifact within the effort to forge intersubjectivity and its spin-off, the individual’s self.

Vygotsky (1930/1978) recognized the role of double stimulation in mediated cognizing: that the subject’s access to an object is mediated by tools such as hammers, names and physical-symbolic inscriptions, so that in higher-order human cognizing we are stimulated by both an intentional object and a cognizing-mediating tool. It is this mediation of cognition by artifacts and via other people that opens the zone of proximal development, allowing the individual mind to first exceed and then later extend its limits. Engeström’s (1987) concept of expansive learning added the cultural dimensions from Marx’ social theory to Vygotsky’s simple triangle of subject-artifact-object. Henceforth, socio-technical understandings of artifacts have to situate them culturally, historically, politically.

We have considered the labyrinthine nature of the artifact’s affordances previously within theories of human-computer interaction (Hutchins, 1999; Norman, 1991), cognitive science (Gibson, 1979; Hutchins, 1996) and CSCL [Investigations 3, 4, 5 and 11]. For instance, based on Merleau-Ponty’s (1945) philosophy, Bonderup Dohn (2009) argued that the affordances of an artifact were potentials realized in response to human behaviors.

The 2012 7(2) issue of *ijCSCL* focused on the role of artifacts in CSCL. The issue opens with Investigation 6, which explores the nature of artifacts by comparing the theory of affordances with the theories of structuration and of instrumental genesis. Structuration (Giddens, 1984; Orlikowski, 2008) is a well-known theory developed to account for the dialectic between social structures and the local interactions, which are both constrained by these structures and reproduce them. Instrumental genesis is a recent theory developed in France by Pierre Rabardel and his colleagues. Investigation 6 introduces the theory of instrumental genesis to the CSCL community and explores how the theory might impact work in CSCL, at methodological, technological, and theoretical levels.

Investigation 6 compares the three major recent theories about the interaction between artifacts and people, using a concrete case study of a typical CSCL setting. It argues in favor of the general approach of instrumental genesis as an analysis of the micro-genesis of artifacts and as the best available description of the nature of tools, particularly for CSCL. The theory of affordances tends to focus on the

individual, for instance with Gibson's biological perspective, Norman's use of mental models, or Piaget's schemas in individual minds. In contrast, the sociological theory of structuration focuses on the societal or cultural level. The theory of instrumental genesis can more naturally be applied to the small-group collective level central to CSCL, as Investigation 6 does in discussing how triads of students enacted a feature of an argumentation-support software system.

Investigation 6 presents a "theoretically grounded" conception of the artifact-agent connection. A next step would be to explore an empirically grounded analysis of the connection. While Investigation 6 referred to data from a CSCL experiment, it simply used high-level descriptions of the data to illustrate aspects of the theories being described. It will be important to also analyze such data in detail to see if the connections of groups of students to computer-support systems follow the contours of one or more of the three theories, or whether they display different lines of development. Furthermore, it will be useful to consider more complex technologies, whole meso-level infrastructures [Investigation 3] rather than isolated functions. For instance, in an online course, small groups may have to negotiate the coordinated use of hundreds of functions in Blackboard, Google search, Wikipedia, Facebook, Google Docs, iChat, Gmail, Word and PowerPoint in order to produce a one-week assignment. Such an undertaking invokes the use of individual experience or expertise, established social practices in the school culture, consideration of course requirements and project goals, as well as collaborative discourse and trials by the small groups. The resultant computer-supported effort assembles and interprets a complex technical infrastructure, increases the expertise of the group participants, and provides a medium for group knowledge building. The connection of the collaborative group with the technical infrastructure continuously evolves through use during an academic term.

Having glimpsed the potential relevance of the theory of instrumental genesis to CSCL, issue 7(2) of *ijCSCL* turns next to a discussion of that theory within the context of CSCL system design. Lonchamp (2012) argues for applying Rabardel's theory by expanding Engeström's (1987) Activity Theory triangle of mediations, to explicitly represent both the processes of mutual shaping of agent and artifact and the specific role of the teacher in CSCL classrooms: He pictures the various mediated interconnections among tool, designer, teacher, student, peer and tutor. Furthermore, he discusses how the agent-artifact connection—embodied in Rabardel's conception of the instrument—evolves over time through usage and re-design.

Lonchamp's paper concludes with a review of CSCL system-design approaches to supporting "instrumentalization" by teachers and students. Although it comes close to describing design-based research (Brown, 1992; DBR Collective, 2003), this review does not name it. DBR is a dominant approach within CSCL research to integrating system design, usage analysis, educational research and practical classroom interventions. It was developed in response to the need to conduct user-centered design of innovative educational software for collaborative groups—a realm lacking in detailed theories, specific analysis methods, adequate software or design guidelines. Perhaps an explicit combination of Rabardel's theory with data from DBR projects could provide empirically grounded insights into the mutual shaping of CSCL software and group cognition in on-going design and usage processes.

The third paper in *ijCSCL* 7(2) is Investigation 7. It situates Rabardel's theory within the context of knowledge-building practices, as these are conceptualized in recent work at the Scandinavian-led Knowledge Practices Laboratory (KP-Lab). This context is populated with social practices grounded in knowledge-building artifacts (Hakkarainen, 2009) and structured in space and time by chronotypes (Ligorio & Ritella, 2010). The knowledge-building artifacts are instruments in Rabardel's sense; they provide for advanced forms of Vygotskian double stimulation (Lund & Rasmussen, 2008). The whole context is the result of the cultural evolution (Donald, 1991; 2001) that led up to our involvement with digital information and communication technologies in an increasingly powerful, distributed, and mediated cognitive universe.

From prehistoric times to the present, the proliferation of forms of inscription (Latour, 1990) transformed the human cognitive architecture as profoundly as earlier leaps in biological evolution, allowing radical externalization and collectivization of cognition. In a sense, CSCL aims to push this further, designing collaboration media to foster group cognition that can lead to new forms of individual learning, team knowledge building, and community social practices. To the extent that this is true, we need to design new tasks for computer-supported teams, aiming for cognitive achievements beyond the reach of individual team members without computer supports. The goal of CSCL research should not be to simply demonstrate repeatedly that individuals learn better in online groups, but to design and investigate tasks that go beyond traditional instruction. Recent findings concerning “productive failure” (Kapur & Kinzer, 2009) illustrate how groups with challenging tasks may be learning in ways that defy standard testing indicators, but that contribute to increased problem-solving skills of the groups and ultimately of their members.

The analysis of instrumental genesis within the framework of knowledge building points to both the potentials of CSCL and the barriers to widespread dissemination. The historical evolution of tools as “epistemic artifacts” can itself be seen as a knowledge-building accomplishment of the greatest cognitive consequence, related to Vygotsky’s—perhaps misleadingly named—notion of “internalization” by individuals of skills germinated in intersubjective circumstances. On the other hand, the complexity involved in successful instrumental genesis translates into severe barriers when, for instance, one tries to promote adoption of CSCL technologies, pedagogies, chronotypes and educational philosophies in established school communities and institutions. Parallel to the difficulties of the students struggling to enact the technological affordances are the difficulties of the researchers, trying to document, analyze and conceptualize the tortuous paths of instrumental genesis in CSCL.

Traversing Planes of Learning

Planes of Learning in CSCL

Learning, cognition and knowledge building can be studied at multiple units of analysis. For instance, analyses of CSCL are often conducted on one of three levels: individual learning, small-group cognition or community knowledge building. One can identify and analyze important processes taking place at each of these levels of description. This tri-partite distinction is grounded in the practices of CSCL. With its focus on collaborative learning, CSCL naturally emphasizes providing support for dyads and small groups working together. In practice, CSCL small-group activities are often orchestrated within a classroom context by providing some initial time for individual activities (such as background reading or homework drill), followed by the small-group work, and then culminating in whole-class sharing of group findings. Thus, the typical classroom practices tend to create three distinguishable levels of activity. Often, the teacher sees the group work as a warm-up or stimulation and preparation for the whole-class discussion, facilitated directly by the teacher. Conversely, the importance of testing individual performance and valuing individual learning positions the group work as a training ground for the individual participants, who are then assessed on their own, outside of the collaborative context. In both of these ways, group cognition tends to be treated as secondary to either individual or community goals. By contrast, the role of intersubjective learning is foundational in Vygotsky (1930/1978), the seminal theoretical source for CSCL. Regardless of which is taken as primary, the three planes are actualized in CSCL practice, and the matter of their relative roles and connections becomes subsequently problematic for CSCL theory (Dillenbourg et al., 1996; Rogoff, 1995; Stahl, 2006).

While these different units, levels, dimensions or planes are intrinsically intertwined, published research efforts generally focus on only one of them and current analytic methodologies are designed for only one. Furthermore, there is little theoretical understanding of how the different planes are connected. To the extent that researchers discuss the connections among levels, they rely upon commonsensical notions of socialization and enculturation—popularizations of traditional social science. There are few explicit empirical analyses of the connections, and it is even hard to find data that would lend itself to conducting such analyses.

The individual student is the traditional default unit of analysis. This assumed approach is supported by widespread training of researchers in the standard methods of psychology and education. In the era of cognitive science, analysis made heavy usage of mental models and representations in the minds of individuals (Gardner, 1985). With the “turn to practice” (Lave & Wenger, 1991; Schatzki, Knorr Cetina & Savigny, 2001), the focus shifted to processes within communities-of-practice. Group cognition lies in the less-well-charted middle ground. It involves the semantics, syntax and pragmatics of natural language, gestures, inscriptions, etc. The meaning-making processes of small-group interaction involve inputs from individuals, based on their interpretation of the on-going context (Stahl, 2006, esp. Ch. 16). They also take into account the larger social/historical/cultural/linguistic context, which they can reproduce and modify.

Computer technologies play a central role in mediating the multi-level, intertwined problem-solving, content-acquiring and knowledge-building processes that take place in CSCL settings. From a CSCL perspective, innovative technologies should be designed to support this mediation. This involves considering within the design process of collaboration environments how to prepare groups, individuals and communities to take advantage of the designed functionality and to promote learning on all planes—e.g., through the provision of resources for teacher professional development, scripted collaboration activities and student curriculum.

The Theory of Interconnected Planes

How are the major planes of learning connected; how can we connect investigations at different units of analysis? To consider a more intuitive physical case initially, a highway ramp or bridge often creates a possibility that did not otherwise exist for going from one level to another at a given point. To traverse from a local road to a limited-access expressway, one must first find an available on-ramp. To cross a river from one side to the other, one may need a bridge. This is the individual driver’s view. From a different vantage point—the perspective of the resource itself—the ramp or the bridge “affords” connecting the levels (Bonderup Dohn, 2009).

By “affords” we do not simply mean that the connecting is a happy characteristic or accidental attribute of the bridge, but that the bridge, by its very nature and design, “opens up” a connection, which connects the banks of the river it spans. In his early work, Heidegger analyzed how the meaning of a tool was determined by the utility of the tool to the human user, within the network of meaning associated with that person’s life and world; in his later writings, he shifted perspective to focus on things like bridges, paintings, sculptures, pitchers and temples in terms of how they themselves opened up new worlds, in which people could then dwell. In considering the intersubjective world in which collaboration takes place on multiple connected levels, we might say that the work of artifacts like bridges is to contribute the spanning of shores within the way that the world through which we travel together is opened up as a shared landscape of places and resources for meaningful discourse and action.

This transformation of perspective away from a human-centered or individual-mind-centered approach became characteristic for innovative theories in the second half of the 20th Century. It is a shift away from the individualistic, psychological view to a concern with how language, tools and other resources of our social life work. It is a post-cognitive move since it rejects the central role of mental

models, representations and computations [Investigation 15]. The things themselves have effective affordances; it is not just a matter of how humans manipulate mental models in which the things are represented to the mind. In phenomenology, Husserl (1929) called for a return to “the things themselves” (*die Sache selbst*) and Heidegger (1950) analyzed “the thing” (*das Ding*) separate from our representation of it. In ethnomethodology, Garfinkel and Sacks (1970) followed Wittgenstein’s (1953) linguistic turn to focus on the language games of words and the use of conversational resources (Stahl, 2006, Ch. 18). In distributed cognition, Hutchins (1996) analyzed the encapsulation of historical cognition in technological instruments. In actor-network theory, Latour (1990) uncovered the agency of various kinds of objects in how they move across levels in enacting social transformations. Vygotsky (1930) used the term “artifact” to refer to both tools and language as mediators of human cognition. The broader term “resource” is frequently used in sociocultural analysis (Furberg, Kluge & Ludvigsen, 2013; Linell, 2001; Suchman, 1987) for entities referenced in discourse. Such artifacts or resources are identifiable units of the physical world (including audible speech and physical gesture) that are involved in meaning-making practices—bridging the classical mind/body divide.

A central research issue for CSCL is how collaborative knowledge building takes place. The main problem seems to be to understand the role of individual cognition and of societal institutions in small-group meaning-making processes. Figure 1 indicates (without claiming to explain or model) some typical processes on each of the primary planes of learning in CSCL and suggests possible paths of influence or connection, as events unfolding on the different planes interpenetrate each other. This figure is not meant to reify different levels or activities, but to sketch some of the constraints between different phenomena and possible flows of influence. The distinctions represented by boxes and arrows in the chart are intended to operationalize an infinitely complex and subtle matter for purposes of concrete analytic work by CSCL researchers.

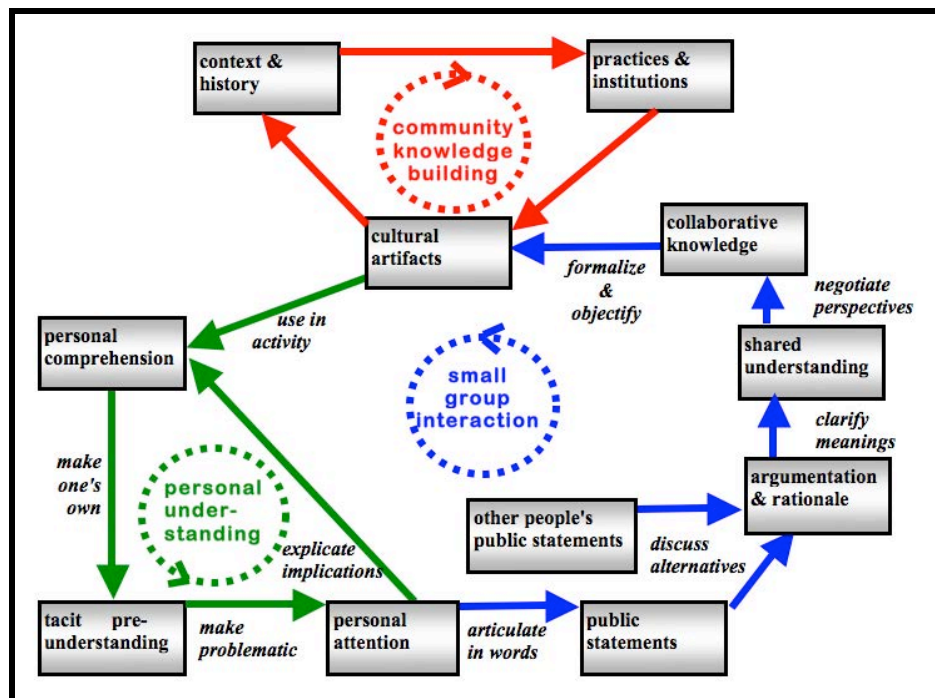


Figure 1. A model of collaborative knowledge building. Adapted from (Stahl, 2006, Ch. 9).

Some researchers, such as many ethnomethodologists, argue against distinguishing levels. For instance, in their description of conversation analysis, Goodwin and Heritage (1990, p. 283) open their presentation with the following claim: “Social interaction is the primordial means through which the

business of the social world is transacted, the identities of its participants are affirmed or denied, and its cultures are transmitted, renewed, and modified.” Social interaction typically takes place in dyads and small groups, so interaction analysis may be considered to be oriented to the small-group unit of analysis. However, CSCL researchers also want to analyze the levels of the individual and the culture as such—e.g., the individual identities and learning changes or the social practices and institutional forces: How do the identities of participants get affirmed or denied as a result of social interaction? How are cultures transmitted, renewed and modified through social interaction?

In general, the sequential small-group interaction brings in resources from the individual, small-group and community planes and involves them in procedures of shared meaning making. This interaction requires co-attention to the resources and thereby shares them among the participants, who co-experience the shared resources. Such a process may result in generating new or modified resources, which can then be retained on the various planes. The resources that are brought in and those that are modified or generated often take the form of designed physical artifacts and sedimented elements of language. We would like to study how this all happens concretely within data collected in CSCL settings.

Resources Across Levels in CSCL

The question of how the local interactional resources that mediate sequential small-group interaction are related to large-scale socio-cultural context as well as to individual learning is an empirical question in each case. There are many ways these connections across levels take place, and it is likely that they often involve mechanisms that are not apparent to participants. In the following, we explore one way of thinking about how such connections can occur: thanks to interactional resources.

In his study of how social institutions can both effect and be effected by small-group interactions, Sawyer (2005, p. 210f) argues that we can conceptualize the interactions between processes at different levels as forms of “collaborative emergence”: “During conversational encounters, interactional frames emerge, and these are collective social facts that can be characterized independently of individuals’ interpretations of them. Once a frame has emerged, it constrains the possibilities for action.” The frames that emerge from small-group interactions can take on institutional or cultural-level powers to influence actions at the individual unit. This interplay among levels involves both *ephemeral* emergents and *stable* emergents. Sawyer’s theory of emergents suggests a relationship among different kinds of resources along the lines pictured in Figure 2.

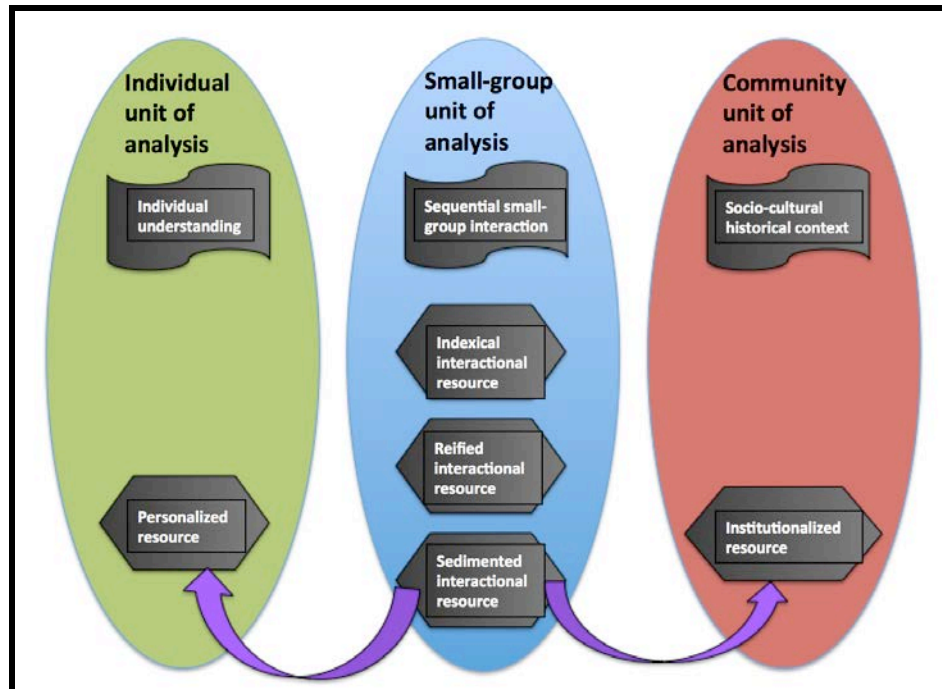


Figure 2. A diagram of emergent interactional resources bridging levels of analysis

While Sawyer’s analysis addresses a broad “sociology of social emergence,” it can be confined and adapted to the concerns of CSCL. What is most relevant in his theory is the view of emergence arising out of the subtle complexities of language usage and small-group interaction—rather than from the law of large numbers, the interaction of simple rules or the chaotic behavior of non-linear relationships. He thereby rejects the relevance of most popular theories of emergence for CSCL and shifts the focus to the discourse at the small-group unit of analysis. The vast variety of interactional emergents form an intermediate level of analysis between the level of individuals and that of community structures, providing a dynamic and processual understanding of social structures and infrastructures. Analysis focused on these emergent artifacts can deconstruct the reifying processes of emergence that span the group level to both the individual and the social.

The small-group interaction represented in the center of Figure 2 can be theorized as being based on an “indexical ground of deictic reference” (Hanks, 1992). This means that the “common ground” (Clark & Brennan, 1991)—which forms a foundation for mutual understanding of what each other says in conversation—consists of a shared system of *indexical-reference resources*, such as deictic pronouns, which are used to point to unstated topics or resources. The coherence of the interaction and its comprehensibility to the group participants is supported by a network of references, each of which is defined indexically, that is by a pointing within the on-going discourse context (“here,” “it,” “now,” “that point”). Interactional resources, which can be indexically referenced in the interaction, can typically only be understood within their discourse context, but they facilitate meaning making within that context [Investigation 5 and 19].

Interactional resources can undergo a process like Rabardel’s instrumental genesis [Investigations 6 and 7]. They may initially be constituted as an object of repeated discussion—an interaction frame (Goffman, 1974)—which we might call a *reified resource*, something capable of being picked out as having at least an “ephemeral-emergent” existence. Through repetition within a group discussion, a term or the use of an object might take on a settled significance within the group’s current work. Over time, continued usage can result in a *sedimented resource*, something whose existence has settled into a longer-term “stable-emergent” form, which retains its meaning across multiple group interactions.

A sedimented resource is susceptible to being taken up by a larger community as an *institutionalized resource* within a structured network of such resources, as in Latour's (2007) social-actor networks, contributing to the socio-cultural-historical context surrounding the interaction. Thus, the institutional resource not only references the social context, but also partially reproduces it in a dialectical relationship of mutual constitution by contributing a new element or revitalizing an old set of resources.

On the other hand, interactional resources at various degrees of reification can also be taken up into the individual understanding of community members as *personalized resources*, integrated more or less into the intra-personal perspective of one or more group members. The personalization of previously inter-personal resources by individuals renders them into resources that can be referenced in activities of individual understanding—corresponding to processes of micro-genesis in Vygotskian internalization.

The various components of this view of interactional resources have been hinted at in previous theoretical contributions grounded in empirical examples. The progressively emergent character of resources can be seen even in fields of mathematics and science, as documented in Investigations in this volume.

The term “reification” goes back to Hegel's dialectical philosophy of mediation (Hegel, 1807). Sfard (Sfard, 2000; 2008; Sfard & Linchevski, 1994) has applied it to the formation of mathematical concepts. Husserl (1936) argued that the ideas of the early geometers became “sedimented” in the cultural heritage of the field of geometry. Livingston (1999) differentiated discovering a mathematical proof from presenting a proof; a transformational process takes place, in which the byways of exploration and possibly even the key insights are suppressed in favor of conforming to the “institutionalized” template of formal deductive reasoning. Netz (1999) (see also the review by Latour, 2008) documented the important role of a controlled (restricted and reified) vocabulary to the development, dissemination and learning of geometry in ancient Greece. Analogously, Lemke (1993) argued that learning the vocabulary of a scientific domain such as school physics is inseparable from learning the science. Vygotsky (1930, esp. pp. 56f) noted that the micro-genetic processes of “personalizing” a group practice into part of one's individual understanding—which he conceptually collected under the title “internalization”—are lengthy, complex, non-transparent and little understood. These seminal writings name the processes of reification, sedimentation, institutionalization and personalization of interactional resources; their empirical investigation poses a major challenge for CSCL research.

Among the theories influential in CSCL—such as activity theory, distributed cognition and actor-network theory—artifacts play a central role as resources for thought and action. In the foundations of activity theory, Vygotsky (1930) conceives of artifacts as including language as well as tools. In his seminal study of distributed cognition, Hutchins (1996) analyzes how the complex of navigational tools, naval procedures for trained teams of people and specialized language work together to accomplish cognitive tasks like ship navigation. He even analyzes data to show how an indexical phrase becomes reified within a dyad's interaction to take on significance that could have led to intra-personal and/or institutional usage. In a witty essay, Latour (1992) shows how a common mechanical door-closer artifact can act to fill the role of an individual person (a doorman), to participate in the politics of a group and to enforce institutional rules. He also argues (Latour, 1990) that an inscription artifact like a map on paper can traverse levels from a local discussion in ancient Asia to the social niveau of imperial Europe. However, studies like these have not often been duplicated in the CSCL literature.

Reviews of CSCL research (Arnseth & Ludvigsen, 2006; Jeong & Hmelo-Silver, 2010) show that few papers in our field have bridged multiple levels of analysis. Yet, the desired CSCL research agenda (Krange & Ludvigsen, 2008; Stahl, Koschmann & Suthers, 2006; Suthers, 2006) calls for a study of representational artifacts and other resources that traverse between individual, small-group and community processes to mediate meaning making. The preceding sketch of a theory of emergent forms of evolving resources could be taken as a refinement of the research agenda for the field of CSCL: a hypothesis about how levels in the analysis of learning are connected; and an agenda for exploration. A

number of Investigations in this volume can be read as beginning such an undertaking. They present examples of interactional resources in small-group discussions and indicate how the resources can be seen as bridging levels of analysis.

Resources for Collaboration and for Mathematics

The idea of viewing interactional resources as central to mathematical discourse around dynamic geometry is proposed in Investigation 9, the first article in *ijCSCL* 2013 issue 8(3). It argues that rather than focusing on the “coordination of interaction” [Interaction 12], collaborative activity should be analyzed in terms of the “coordinated use of resources.” Participants rely on two major categories of resources when working on a geometry problem within a computer-based dynamic-geometry environment: (1) mathematical and tool-enabled resources (math-content-related) and (2) collaboration resources (relational or social). In Investigation 9, Öner proposes a focus on the coordination of these resources—which characterize collaborative dynamic-geometry problem solving—for understanding what goes on in such productive math learning.

The combination of social and content resources brought to bear on geometric problem solving often bridges levels. Social resources—such as greetings, invitations to speak, checks on discourse direction—function to cohere the group out of its individual members, drawing upon community standards and institutional routines. Uses of math resources—such as manipulating visual representations, referencing recent findings, expressing relationships symbolically—move fluidly between individual perceptual behavior, group problem-solving sequences and the cultural stockpile of mathematical knowledge. Perhaps the incessant traversal of levels is particularly visible in collaborative math discourse because of its explicit use of multiple layers of reality: a physical drawing, the intended figure, a narrative description, a symbolic expression, the conceptualization, the mathematical object.

Öner’s methodological proposal is to trace both the math-content-related and the social/collaborative/relational resources used by students solving dynamic-geometry problems. Math resources may come from graphical, narrative and symbolic representations or expressions of the math problem or from previous math knowledge of culturally transmitted concepts, theorems, procedures, symbolisms, etc. Social resources include communication practices, such as the rules of conversational discourse (transitivity, sequentiality, shared attention, argumentation, turn taking, repair, etc.).

Öner’s Investigation cites a number of distinctions drawn in the CSCL literature for contrasting social/collaborative/relational resources with content-related resources:

- An inter-personal-relations space versus a content space (Barron, 2000);
- Building a joint problem space (JPS) versus solving a problem (Roschelle & Teasley, 1995);
- Temporal dimensions of the JPS versus diachronic content (Sarmiento & Stahl, 2008);
- Text chat versus shared-whiteboard graphics (Çakir, Zemel & Stahl, 2009);
- Project discourse versus mathematical discourse (Evans, Feenstra, Ryon & McNeill, 2011);
- Spatio-graphical observation (SG) versus technical reflection (T) (Laborde, 2004).

The “space” that a group builds up and shares is a structured set of resources gathered by the group (JPS, indexical field, common ground). The resources are “indexical” in the sense that they are only defined within (and thanks to) this constructed space of the specific problem context. Through their discourse, the group compiles these resources as potentially relevant to the problem. In turn, the resources help to define the emergent problem, dialectically.

Öner generated data to explore the interaction of the contrasting dimensions by having two people work together face-to-face in front of a shared computer on a particular dynamic-geometry problem, whose solution required a mix of spatio-graphical observation and technical reflection involving mathematical theory—a mix of SG and T resources, to use the distinction she adopts from Laborde. She

uses this distinction among resources to structure her analysis. In doing so, she shows how these various resources bridge the different units of analysis. Resources of *individual* perception (during dragging of geometric objects on the computer screen) feed into the *group* problem solving, just as do references to classical theorems passed down through *cultural* institutions. They make possible and stimulate the group interaction. This analysis provides examples of interactional resources at work in CSCL settings.

By analyzing both social and content resources, Öner shows how interrelated these can be. For instance, at one point in the data, one student says, “now two isosceles, oops, equilateral triangles are formed here.” This utterance is deeply indexical. It is pointing to the “here” and “now” of the geometric construction. The student is narrating his work, intersecting two circles to locate the vertices of the desired equilateral triangle (see Figure 3). The method he is using refers back over 2,500 years to Euclid’s first proposition, which teaches this construction. It also notes that one could use either of two potential intersections to construct alternative triangles. This leads his partner to see first one of the intersection points and then the other. Öner notes that the two students collaboratively accomplished this construction; in the doing of it, they collectively recalled the procedure, which they had performed in the past but forgotten. She also emphasizes that this utterance includes a self-repair, in which the speaker substitutes a correct term (“equilateral”) for an incorrect one—a move she considers social. Repairs are conversational moves aimed at avoiding or correcting potential misunderstandings.

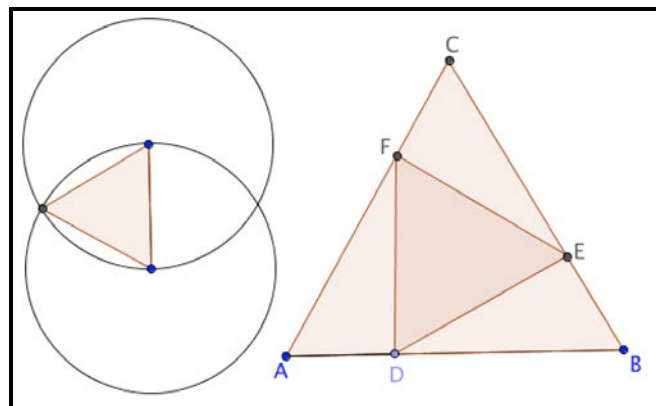


Figure 3. Constructing an equilateral triangle inscribed in an equilateral triangle.

This raises a key theoretical point. Should this utterance be analyzed, categorized or coded as a social resource or as a mathematical one? What is the resource here? Is it the generic conversational resource of self-repair as a “member method” (Garfinkel, 1967), or is it the word “equilateral” in the shared language, or is it the geometric concept of equilateral polygon? I.e., is it a conversational move, a linguistic term or a mathematical concept? This is a matter of level of analysis, because one could characterize it in any of these ways. Alternatively, one could argue that the interactional resource that exists here spans multiple levels of analysis, providing an object for analysis at the conversational, linguistic and mathematical levels of the interacting group, the speaking individual and the cultural conceptualization. In other words, such a resource can serve as a boundary object (Star, 1989), which can be discussed from different perspectives, focused on different units of analysis.

Öner succeeds in analyzing how her students collaborated on their geometry problem by focusing consistently on the interplay between social and content resources. It may be that we can often follow the movement of discourses across different levels by keeping our eyes on consequential resources. However, other CSCL researchers interpret the theme of resources differently from Öner. This leads them to different insights about their data. Perhaps we can use the concept of resource as a methodological boundary object to bring together the disparate theoretical voices. Too often, they seem to talk at cross-purposes, emphasizing differences when they might well be seeing the same phenomenon from different angles.

Scientific Representations across Levels

Even if analysts agree in identifying a certain object as a pivotal interactional resource, that does not mean that the nature or meaning of that resource is self-evident to students using it for collaborative learning—as the second article in *ijCSCL* 8(3) by *Anniken Furberg, Anders Klug and Sten Ludvigsen* (2013) makes clear. They turn to look at how students make sense of scientific diagrams to support their collaborative learning of physics. The implications of a diagram of a photoelectric cell only emerge gradually for a group of students striving to understand and explain the scientific processes represented there.

The central case study of this paper illustrates how the students gradually produce the meaning of the scientific representation. It is the sense-making process—mediated by the representational resource—that spans levels: The individuals, each with their own approaches and each bringing in different other resources, contribute to the group's collaborative effort, resulting in a group understanding, expressed however awkwardly and partially in their written report. The representation—first from their textbook and then complemented with a second diagram from the Internet—is a contribution from the larger scientific or science-education community.

The paper characterizes the science diagram as a *structuring resource*. It argues that the representation, as it becomes meaningful to the students, structures the group's sense-making work. The structuring takes place on various levels: Interactionally, the group uses the diagram as a deictic resource, pointing to its features either gesturally or linguistically to support the verbal accounts. Individually, the students refer to the diagrams to monitor their own understanding. At the level of science norms, the students attempt to use canonical language to express the sense they are making of the diagram.

Student discourse generally halts in articulation of an idea at the point when everyone seems to understand each other adequately for all practical purposes of the conversation. Even adding a third person to the discourse can extend the discussion somewhat, because the third person brings new questions and needs for understanding. However, when students go to write up a point, they must attain a much higher standard of articulation. They must make their written statement comprehensible and persuasive for a general audience or for people not present to indicate their understanding or agreement. This audience might, for instance, include the teacher, other students in the class or even an audience of unknown potential readers. The audience might require a scientific formulation, using the vocabulary and stylistic genre of physics. Furthermore, since the reading audience is not co-present with the speakers, physical gestures and deictic references to times, places, people and objects present are no longer effective. While the diagram still helps to structure their articulation of the description, the description can no longer rely so heavily on the diagram to help convey their meaning.

It is always true that there is a dialectical circularity or recursive character to the relationship of the discourse context and the utterances that are made within that context; this becomes even clearer in the relationship of the diagram as a structuring and interactional resource to the students' understanding of this resource. The (tentatively understood) diagram helps to structure the students' (increasing) understanding of the diagram itself. The paper nicely shows how the introduction of a second diagram enriches the dialectic by shedding light on the first diagram's meaning through the tension created by the differences between the two representations.

Referential Resources for a Math Problem

In the third paper of *ijCSCL* 8(3), Investigation 5 takes an ethnomethodologically informed look at the role of resources, representations, referential practices and indexical properties in the mathematical problem-solving interactions of students within a CSCL setting. Viewed in the context of the 8(3) issue of *ijCSCL*, Investigation 5 develops further some of the central themes of the two previous papers. It concurs with the first paper on the importance of tracking the use of resources, and it further emphasizes that it is the on-going specification-in-use that determines the significance of a given resource. It concurs with the

second, in adopting a concern with representations, and it makes even more explicit the extent to which the representational practices—how the representation was built and worked with—contribute to the problem clarification and problem solution.

In theoretical terms, this paper develops the discussion of *indexical reference resources* by Hanks (1992). It considers two groups of students who were presented with the same problem statement involving combinatorics. The two groups identified completely different sets of “indexical properties,” which allowed them to formulate implicitly, share collaboratively and solve mathematically the “same” problem, which, however, had been specified quite differently. In the first team, Bwang8 specified the stair-step pattern of squares in terms of two symmetric sets of lines. Each set of lines followed the pattern: 1, 2, 3, ..., n, n. In the second team, Davidcyl specified the problem initially as: “the n^{th} pattern has n more squares than the $(n-1)^{\text{th}}$ pattern.”

Ethnomethodologists are keen to observe the “work” that people do to accomplish what they do. Both teams engaged in intricate coordination of text understanding, sequential drawing, retroactive narrative and symbolic manipulation to make sense of the problem statement they faced and to arrive at a mathematical solution. The work involved in this can be characterized as discovering, proposing and negotiating successive determinations of indexical properties of the problem they were working on. The indexical properties are ways in which the team members can reference aspects of the problem, such as in terms of sets of lines arrayed in specific identifiable patterns. These indexical properties are tied to the local problem-solving context of the respective team. They specify the problem for the team in practical terms, which allow the team to make progress in both understanding and solving the problem.

This approach is appropriate for what Rittel and Webber (1984) called “wicked problems.” These are non-standard problems, for which the approach to problem solving is not obvious and turns out to be a matter of coming to understand the problem itself. One can imagine Bwang8 entering a completely unknown territory. He was not familiar with the online environment, had never seen the kind of problem statement that was displayed, did not know the other team members and was unclear about what was expected of him. He spotted (visually) an interesting symmetry in the problem and started by stating it as an initial specification about how to view (perceptually and conceptually) the problem. Then he started to draw the problem, so specified, on the shared whiteboard. Davidcyl entered a similarly unknown territory. He started drawing the pattern for $N=4$, as suggested in the text. In so doing, he developed some copy-and-paste practices, which he presented (in the sequentiality of his drawing process as well as in his accompanying description) as tentatively mathematically relevant.

Starting from *individual* suggestions of indexical properties (by Bwang8 or Davidcyl, respectively), each group developed a growing shared indexical ground of deictic reference. The work of building that space of possible references led the *group* to make sense of a problem and to discover a path to a solution in mathematical terms. The ground itself is a set of shared interactional resources that allows the team to refer to its object of concern in mutually intelligible ways. By gradually moving from purely deictic terms like “it” or “this,” to mathematical terms or abstract symbols, the indexical resources incorporated cultural knowledge and contributed to a less locally situated store of understanding that could be relevant in a larger classroom or *culture* of school mathematics (including standardized tests). The analysis of how these groups successively and collaboratively re-specify their referential resources suggests approaches to studying how groups make sense of problems and artifacts whose indexical properties are initially unknown or underspecified. This is a foundational concern for CSCL, as “a field of study centrally concerned with meaning and the practices of meaning making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts” (Koschmann, 2002).

Roles as Interactional Resources for Community Meaning Making

If the previous studies take interactional approaches, the next paper in *ijCSCL* 8(3), Hontvedt and Arnseth (2013), can be considered to be largely at the community-of-practice level. Like the apprenticeship cases of Lave and Wenger (1991), this one is concerned with how novices take on the practices of a professional community. Situated in a simulator for training Norwegian sailors, the apprentices role-play at navigating a ship. To bring a ship up the fjord to Oslo, they must bring aboard a local expert. This master pilot helps to establish the professional navigational practices with the apprentices. Interestingly, the pilot insists on using the international language of shipping, English. At times, the trainees slip into Norwegian to reflect on their role-playing, thus marking linguistically the duality of their realities. On the one hand, they are playing the roles of professional sailors interacting in English on the bridge with the local pilot; on the other, they are Norwegian students discussing their educational activities.

Through their role-playing, the participants—whether newcomers or established members of the sailing community—co-create interactionally the context of their learning. Much of the learning consists in this subtle process, which includes integrating interpersonal relations, language constructs, physical artifacts, a designed setting and nautical tasks. Together, this constitutes what the authors call an *activity context*. Building on the theoretical framework of activity theory, an activity context is closely related to Goffman's (1974) concept of frame.

The roles taken on by the students are resources for their apprenticeship meaning making. Like roles in a play on stage, they require a willing suspension of disbelief. The analysis in the paper nicely shows how the students fluidly move in and out of their roles and negotiate when to do so, often through code switching between the languages of the two cultures. Never taking the simulation fiction too seriously—as though it were an immutable reality—the analysis reveals how the participants themselves achieve the tenuous existence of the activity context interactionally.

The interactional resources of this learning community are ephemeral emergents—which also means they can collapse. The action can call for a role or an artifact that is missing from the simulation, resulting in improvisation, chaos, laughter. This carries a lesson for all of us: an assemblage of resources for learning cannot foresee all uses. Even the most rehearsed experiment in complex learning is likely to run afoul of glitches. In the best cases, the participants laugh off the troubles ... and the analysts discover insights in the breakdowns.

Annotations as Resources for Individual Learning

In the final paper of issue *ijCSCL* 8(3), Eryilmaz et al. (2013) take a controlled-experiment approach to evaluate the effect of a promising annotation-support tool as a resource for individual learning. While acknowledging that online asynchronous discussion in a university course is a group activity in an educational social setting (with an instructor, discourse standards, canonical texts, grading, etc.), the authors systematically focus on the learning of individual students as evidenced by their individual postings and isolated pre-/post-tests. In contrast to the qualitative analysis of interaction in the preceding papers, this one codes individual posts and analyzes them with a battery of quantitative methods. Even the analysis of sequentiality is done without reference to interactional context. The group and social setting are considered controlled for, and only the presence of the software function distinguishes the treatment from the control condition.

By methodologically focusing on the individual student and the individual posting as the units of analysis, this study is able to isolate and quantitatively assess the role of context on these units. For instance, the paper asserts that, “collaborating students are able to use one another as a *resource for learning*” (emphasis added). That is, while learning is conceptualized as a process that primarily takes place in individual heads, it is enhanced by the interactional level of individuals formulating ideas as posted text and receiving feedback as posted responses from others. Asynchronous discussion forums

seem like good media for supporting such enhancement, except that their use apparently causes excessive “cognitive load,” reducing the ability to engage in the cognitive processes required for deep learning and therefore counteracting the potential benefits of social interaction.

The complex socio-cultural and interactional processes analyzed in the previous papers are here viewed as likely sources of unwelcome cognitive load. In order to communicate one's ideas about a text in annotations that might make sense to other students, one must engage in the sorts of collaborative meaning making analyzed in the other papers. For instance, one must construct explicit indexical references, such as “the third sentence in the conclusion,” which can be used to coordinate co-attention.

To make it easier to establish joint reference, the authors of this study provided students with a software indexing function, which graphically connects annotations with relevant selections in the provided educational text. The treatment group uses this software tool as an *interactional resource*, which is not made available to the control group. The research then studies the effect of the resource on learning with the rigor of its chosen methodology. The study shows that the treatment group produces more posts coded as “assertions” and “conflicts.” It also does better than the control on the post-test, confirming experimental hypotheses. The conclusion is that the software resource reduced the cognitive load needed to co-construct effective shared interactional resources, like indexical descriptions of target text passages. This allowed the students more cognitive ability—or perhaps just more time-on-task—to engage in interactive assertions and conflicts. So the focus on the individual unit of analysis allowed this study to evaluate interactions between individual learning, group interaction and socio-technical setting.

Of course, one can always question a study's assumptions and operationalization. The recent findings in CSCL research about “productive failure” (Kapur & Bielaczyck, 2012; Kapur & Kinzer, 2009; Pathak et al., 2011) problematize the purely negative view of what is here characterized as cognitive load, as well as the way of assessing deep learning. Positive findings about productive failure suggest that group processes can underlie learning in ways that may not show up immediately. The effort (cognitive load) to build a joint problem space about a text through interpersonal interaction may confer learning benefits that are not achieved when that task is delegated to software. The benefits may also not show up in measurements taken immediately at the individual unit of analysis.

This final paper of the *ijCSCL* issue, taken together with the preceding four, illustrates how different methodologies can be adopted for analyzing resources and their relations to different levels of analysis. What can be taken as a resource for purposes of CSCL research is open to a broad range of approaches and theoretical frameworks. One can find resources for individuals, groups and communities. Often, those resources can be seen as traversing across or mediating between levels. Analysts can fruitfully focus on one aspect or another of this; or they can strive to follow resources across multiple levels.

The CSCL Agenda on Levels of Analysis

The time has come for CSCL to address the problem of traversing levels of analysis with exacting research. Attempts to research a given level in isolation have run into fundamental limitations. Although it is clear to most researchers that the levels of individual, small-group and community phenomena are inextricably intertwined, opinions differ on how to respond analytically. Religious wars between adherents of different methodological faiths are often based on misunderstandings: people agree on the need to comprehend the levels together, but articulate that need in incommensurate-seeming locutions.

Multiple-method approaches, multi-level statistics and multi-vocal analyses are too limited, because they do not explicitly address the interrelationships among different levels. Some researchers claim that the apparent levels are all reducible to one fundamental level—whether individual cognition, group interaction or the social—while others assume that they can be studied independently. Some say that there is no such thing as different levels, but only different kinds of analysis, although they generally end up talking of individual understandings, group interactions and community practices. There are vague

theories that one level is emergent from another or dialectically coupled with it, but these ties are not well worked out or evidenced with CSCL data.

The contributions in this issue provide examples of the kinds of studies and analyses that are needed. In order to comply with one or another standard of rigor, most research focuses on specific relationships within a single unit of analysis. We now also need to generate, compile and analyze data that sheds light on relationships across levels. The idea of tracking *interactional resources* as they mediate across levels offers one suggestive approach. The different papers discussed here and other referenced theories show that there are many ways to conceptualize, analyze and theorize resources. We do not mean to define or defend a particular tack, but to suggest interactional resources as a candidate boundary object for discussion across competing approaches. We do not claim to have proposed a consistent position, but rather to raise some questions about what can be meant by resources for computer-supported collaborative learning, in the hope of stimulating thinking for CSCL research in the future.

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