Exploring Adaptive Support for Virtual Math Teams

1. Vision

American children are in the middle of a group of 38 countries in terms of science and math education, far behind such countries as Singapore, Korea, Hong Kong or Japan (Mullis et al., 2000). On-line learning promises to address this problem by providing free or inexpensive education for the masses – quality educational opportunities available to all people, but especially those who are in the greatest need – although this dream is yet to be made a reality. The ultimate goal of the proposed work is to replicate the impact of what are normally local, on-campus programs targeting increased college preparedness and college success of minority and low income students, such as the Professional Development Program (PDP) (Treisman, 1985), in a freely available, on-line learning environment. We focus on middle school math since middle school is a pivotal time when students, especially girls, begin to lose confidence in and interest in math (Callahan & Clements, 1984; Dossey, Mulis, Lindquist, & Chambers, 1988; Brandon & Newton, 1985), and we target the well established Virtual Math Teams (VMT) online math service at http://mathforum.org/vmt as a venue for broad dissemination. Furthermore, we focus on eliciting proof-like explanations from students, since this is an important skill connected with a deep understanding of math concepts (Ma, 1999; Aleven & Koedinger, 2002; Hanna, 1990; Hanna, 1995; Hersh, 1993), and which continues to be a struggle for students throughout their school years (Moss & Beatty, 2006; Harel & Sowder, 1998). This proposed project brings together a team with expertise in both technological development and careful experimentation both in the lab and in the classroom, a track record for large scale deployment of educational materials, a solid foundation in significant results from prior work on which we build in the areas of computer supported collaborative learning and tutorial dialogue systems.

The purpose of this exploratory project is to lay the foundation for a longer term project seeking to enhance participation and learning in the Virtual Math Teams (VMT) online math service by designing, developing, implementing, testing, refining and deploying computer-supported tools to support facilitation in this lightly-staffed service. The key research goal in the long term is to optimize a design and implementation for adaptive feedback in support of collaborative problem solving that will maximize the pedagogical effectiveness of the collaboration by eliciting behavior that is productive for student learning in collaborative contexts. This will be accomplished through close collaboration among CMU, Math Forum and VMT researchers. As a starting place, in this exploratory project we will begin this process by beginning to integrate our research findings and infrastructure from our prior work in the areas of computer supported collaborative learning and tutorial dialogue systems. We will also pilot our integrated VMT environment in order to collect realistic data so that our plans for our continued collaboration can be strongly influenced by observations of interactions in the exact environment where we plan to work towards a significant impact in the long run. In our exploratory data analysis we will take a qualitative approach so that we can get a firm handle on important contextual variables that we will take into account in our subsequent experimental work.

2. Building a Foundation by Integrating our Prior Work

Our research goal is supporting productive collaborative learning discussions in a computer-mediated environment in “the wild”, specifically supporting students in working together in pedagogically effective ways. Researchers have examined the mechanisms by which human tutors are so successful at teaching and motivating children as a model of successful education (Bloom, 1984; Cohen, Kulik & Kulik, 1982). Unfortunately, it is not practical to provide every student with a human tutor. While there is a shortage in terms of the resources to provide each student with their own tutor, there is no lack of children in need. While the help students are capable of offering one another is not perfect, there is evidence that it is effective in spite of the errors students make when helping each other (Gweon et al., 2006; Gweon et al., submitted), and possibly even because of these errors (Piaget, 1985; De Lisi & Goldbeck, 1999; Grosse and Renkl, submitted). If we can harness the potential of state-of-the-art technology for automatically filtering collaborative learning discussions that we have developed in our previous work (Donmez et al., 2005; Wang et al., submitted), and we can use this automatic analysis to trigger interventions that support students in helping each other learn together (Gweon et al., 2006) using tutorial dialogue and intelligent tutoring technology, we could move towards a solution to our nation's educational problems in a cost effective, practical manner. In this section we describe how we integrate elements from our previous work into a technical foundation as well as a foundational instructional approach that we build on and extend in our proposed work.

For a technological foundation, the CMU team brings to the project much prior work developing and evaluating tutorial dialogue technology that can be used to deliver interactive support (Rosé et al., 2001; Gweon et al., 2005; Rosé et al., in press; Rosé et al., 2005; Kumar et al., 2006; Wang et al., 2006-a), prior work developing automatic collaborative learning process analysis technology that can be used to trigger interventions (Donmez et al., 2005; Wang et al., submitted), other language technologies research related to text classification (Rosé et al., 2003; Rosé et al., 2005; Donmez et al., submitted), robust analysis of explanations (Rosé, 2000; Rosé et al., 2002; Rosé & VanLehn, 2005) and dialogue analysis more generally (Rosé et al., 1995; Arguello & Rosé, 2006; Wang et al., 2006-b), as well as work on design and evaluation of adaptive collaborative learning support (Gweon et al., 2006; Wang et al., submitted-b; Kumar et al., submitted) and investigations of group composition and gender effects in collaborative learning in an intelligent tutoring environment (Gweon et al., 2005; Gweon et al., submitted).

The Drexel team brings the existing Virtual Math Teams (VMT) environment (http://mathforum.org/vmt). The Virtual Math Teams (VMT) project within the Math Forum uses peer collaboration in small student teams to enhance learning and participation in math discourse. Small groups of students are invited to chat rooms (see description of the Collaborative Environment in Section 4.1) where they discuss carefully designed math problems or math micro-worlds. VMT mentors are typically not present in the chat rooms, but they provide asynchronous feedback to the student groups upon request. We proposed to augment this environment with automatic, adaptive collaboration support. Math Forum and VMT staff will be involved at all stages of designing, developing, implementing, testing, refining and deploying these computer-support tools in close collaboration with researchers from Carnegie Mellon University. VMT researchers have extensive experience exploring the effectiveness of these materials for stimulating productive collaborative learning interactions. For analysis of collaborative discussions, VMT researchers have used a variety of methods that we will draw upon in our proposed work for on-line and off-line analysis of the learning and collaboration that takes place in the VMT-Chat environment, including statistical analysis of coded chats, ethnographic observation of participation and interaction analysis (adapting ethnomethodologically-informed conversation analysis to textual chat). A large number of studies of VMT chats are already available, including (Cakir *et al.*, 2005; Sarmiento, Trausan-Matu, & Stahl, 2005; Stahl, 2006a, 2006b, 2006c, 2006d, 2006e; Strijbos & Stahl, 2005; Wessner *et al.*, 2006; Zemel, Xhafa, & Cakir, 2005); see http://www.mathforum.org/vmt/researchers/publications.html for a more complete list.

Our instructional approach is modeled after constructivist principles of classroom discourse, such as those advocated in (Chapin, O'Connor, & Anderson, 2003). Our goal is to maximize the benefit students receive from the interactions they have with one another. Not all instructional conversation between learners is equally effective, and often requires some form of support in order to become effective (Weinberger et al., 2003; Rummel et al., 2003). Webb and colleagues present a series of studies in different educational settings that demonstrate the importance of the depth of instructional explanations, both for the speaker as well as the recipient (Webb, 1991; Webb, Nemer, & Zuniga, 2002). Much research shows the value of drawing out student reasoning in the form of elaborated explanations. In particular, one of the best substantiated educational findings in cognitive science research related to education is the educational benefit of explanation, and in particular, the self-explanation effect (Chi et al., 1989; Chi et al., 1994; Chi, 2000). Nevertheless, previous discourse analyses of collaborative conversations reveal that the majority of conversational interactions between students do not display the "higher order thinking" that collaborative learning is meant to elicit (Webb & Mastergoerge, 2003; Webb, Nemer, & Zuniga, 2002), and we have found this as well in our own observations of collaborative learning, both at the college level (Gweon et al., 2006) and at the middle school level (Gweon et al., submitted).

State-of-the-art approaches to collaborative learning support are static one-size-fits-all approaches such as scripts (O'Donnel, 1999; Kollar et al., 2003), structured interfaces (Robertson et al., 1998; Baker & Lund, 1997), and collaboration training videos or other modeling techniques (Rummet et al., 2006). To begin to move past the traditional one-size-fits-all non-adaptive approaches to collaboration support, we have conducted a series of studies in which we experimentally investigate foundational issues related to the design of adaptive support for on-line collaborative learning (Gweon et al., 2006). These initial investigations demonstrated that explanation elicitation prompts delivered strategically, on an as needed basis, were effective for eliciting explanation attempts as well as increasing learning. In our long term plans in the VMT context, in order to elicit the type of collaborative behavior that leads to more learning, we will use adaptive collaboration support in the style of our previous investigations at the secondary and post-secondary level (Gweon et al., 2006; Wang et al., submitted-b; Kumar et al., submitted). Our previous success with automating collaborative learning process analysis (Donmez et al., 2005) offers promise that the adaptive support mechanism evaluated using a Wizard-of-Oz setup in (Gweon et al., 2006) can be implemented and deployed fully automatically. We have achieved near human reliability at applying a sophisticated multi-dimensional collaborative process analysis coding scheme describe in (Weinberger & Fischer, submitted; Fischer et al., 2002) to a corpus of newsgroup style collaborative learning interactions using our novel text classification technology. We have also run two successful studies in which we used dialogue agents to deliver interactive support when triggered by an automatic analysis of the collaborative learning discussions as they unfolded (Wang et al., submitted-b; Kumar et al., submitted). In both of these successful studies, the fully automatic interactive support lead to significant increases in learning in comparison to a control condition that did not have the interactive support. However, neither of these studies took place in an open web environment such as the Virtual Math Teams environment. Thus, there is still much work to do to investigate how best to support collaborative learning in an environment such as this.

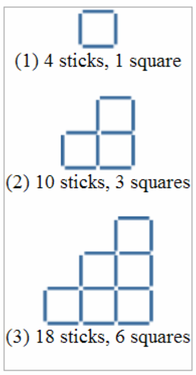
3. Math Forum Materials

Selecting appropriate materials to stimulate productive collaborative conversations is essential to the success of collaborative learning. Since the goal of much collaborative learning is to stimulate higher order thinking, typical tasks used in studies of collaborative learning are open ended problems with multiple possible solutions, especially ones with many trade-offs rather than right versus wrong solutions, or highly interpretative problems such as case study analysis. We draw from resources designed by The Math Forum, which has been providing a successful, highly popular online community and digital library for K-12 students, teachers and others for over a decade (Renninger & Shumar, 2002). Although the Math Forum works closely with school districts and teachers, its central focus is on providing informal learning experiences, by developing challenging, non-traditional math problems for students to think about and by collecting student responses. Although it has collected some of these responses into math books on algebra and geometry, it mainly organizes these responses as a digital library. In its various services (see Section 6 on Partnerships and http://mathforum.org for more details), the Math Forum facilitates interactions among students, teachers, pre-service teachers, volunteer mentors and paid staff.

An example problem is displayed in Figure 1. In the VMT environment, students work in small groups on the same problem over 3 sessions. In the first session, they work out solutions to the problem. In between the first and second sessions, students receive feedback on their solutions. In the second session, students discuss the feedback they received on their respective solutions and step carefully through alternative correct solutions. In that session and the subsequent session, they also discuss additional possible ways of looking at the problem including variations on that problem in order to take a step back and learn larger mathematics principles that apply to classes of problems rather than individual problems. Although the problem provides the opportunity to investigate multiple possible solutions and to engage in deep mathematical reasoning, our finding from analysis of chat logs where students have worked on this and other problems is that students tend to jump to finding one solution that works rather than taking the opportunity to search for alternative solutions. The moderator plays an important role in stimulating conversation between students, encouraging knowledge sharing and probing beyond a single acceptable solution. Thus, we plan to model our adaptive support agents after successful group moderators using a similar data driven process that was used to develop the CycleTalk tutorial dialogue agents (Rosé et al., in press; Kumar et al., 2006) after successful human tutors (Rosé et al., 2005) supporting learning in the same environment that the chat agents now participate in.

VMT Spring Fest

Here are the first few examples of a particular pattern or sequence, which is made using sticks to form connected squares:



N	Sticks	Squares
1	4	1
2	10	3
3	18	6
4	?	?
5	?	?
6	?	?
...	...	...
N	?	?

1. Draw the pattern for N=4, N=5, and N=6 in the whiteboard. Discuss as a group: How does the graphic pattern grow?
2. Fill in the cells of the table for sticks and squares in rows N=4, N=5, and N=6. Once you agree on these results, post them on the VMT Wiki
3. Can your group see a pattern of growth for the number of sticks and squares? When you are ready, post your ideas about the pattern of growth on the VMT Wiki.

Figure 1 Example Math Forum Problem: The Sticks Problem

4. Building on and Extending the Technological Infrastructure

4.1 Collaborative Environment

The Math Forum and its Virtual Math Teams Project will collaborate with CMU personnel under this grant in the exploratory work towards designing, developing, implementing, testing, refining and deploying of the computer-support tools that are part of this grant. In particular, the VMT-Chat environment will be available as a test-bed for collecting data about the performance of these tools. VMT staff will be involved in assessing the results of the use of these tools through close analysis of selected excerpts from this chat log data. The free VMT service currently consists of an introductory web portal within the Math Forum site (http://mathforum.org/vmt) and an interactive environment called VMT-Chat. VMT-Chat includes the VMT Lobby, where people can select chat rooms to enter, and a number of math discussion chat rooms, that each include a text chat window, a shared drawing area and a number of related tools (for a more detailed description of the environment and how it is used, see (Stahl, 2006). The environment is available as Open Source, so that (1) it can easily be extended for this project and (2) the results of this project can easily be made available to other researchers.

4.2 Architecture for Adaptive Collaborative Learning Support

In Figure 2 below is displayed the architecture of the adaptive collaborative learning support system developed at Carnegie Mellon University, and evaluated in the domains of Earth Sciences (Wang et al., submitted-b) and thermodynamics (Kumar et al., submitted). In both cases, our finding was that students who collaborated with the adaptive support through intelligent dialogue agents learned significantly more within the same amount of time as pairs who worked together without this support. In this architectures, students communicate with each other and with the intelligent agents through a chat interface. A server coordinator module collected their conversational contributions in order to send them on to other system modules as well as to accumulate a conversational history that was displayed to students in their chat interface. Conversational contributions were first passed to a filter module that applied text classification technology in order to detect important conversational events. These events, when detected, were indicated to an Interaction Module, which then updated it's model of the conversational state. In certain states, a trigger was then sent to the intelligent agent, eliciting it's support in the conversation. The conversational behavior of the agent was tailored according to the specific trigger sent.

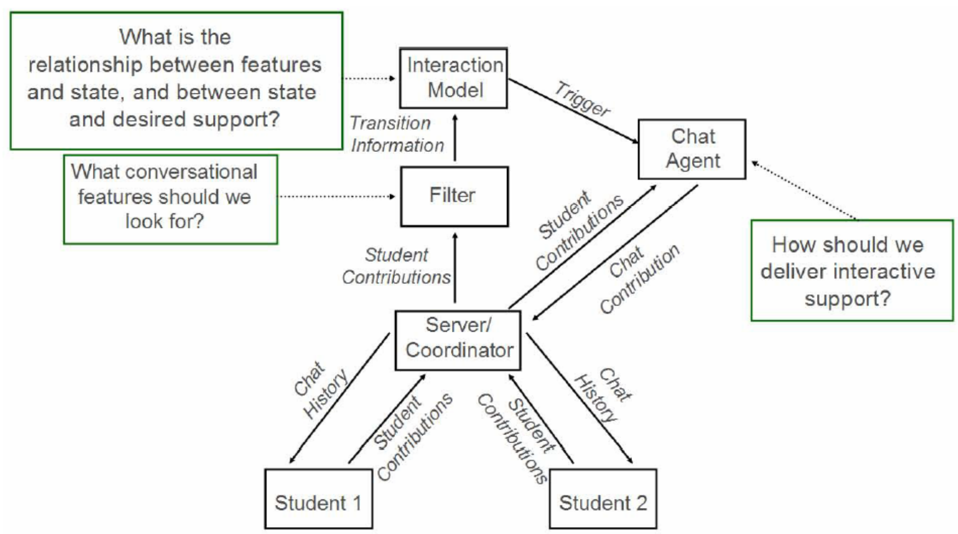


Figure 2 Architecture for Adaptive Collaborative Learning Support

Note, as displayed in Figure 2, that this architecture allows for specialization of the design in three main ways. First, the Filter module can be tailored to perform a wide range of types of collaborative learning process analyses. Furthermore, at a more abstract level, the manner in which evidence of individual conversational events in assessing conversational state can be specialized depending upon the assessment approach as well as the model of scaffolding and fading of support in collaborative learning. Finally, the form of the delivered support can be modified by replacing or modifying the intelligent dialogue agents.

In both of our evaluations of this architecture of adaptive support, we have used a simple topic oriented filter to detect when important topics are raised throughout the conversation. However, our work on automatic collaborative learning process analysis offers evidence that we can implement much more sophisticated collaborative learning process modeling approaches. Specifically, as part of a collaboration with the Knowledge Media Research Center in Tuebingen, Germany, we have developed a proof of concept for fully automatic collaborative learning process analysis (Donmez et al., 2005; Wang et al., submitted). In this sophisticated coding scheme, each span of text is assigned multiple labels, each of which offers a different perspective on the nature of the contribution, often drawing upon information of a different nature from the other dimensions. For example, the Micro and Macro dimensions each characterize different aspects of the linguistic structure of the contributions whereas the Social Modes, Reaction, and Appropriateness dimensions focus on different types of social conventions and relational styles conveyed in and encoded in contributions.

5. Research Plan

The proposed work for this small exploratory project will be conducted partly at Drexel University and partly at Carnegie Mellon University. The work at Drexel University will begin earlier than the work at Carnegie Mellon University. The work at Drexel University, headed up by Gerry Stahl and Steven Weimer will include collecting a corpus of example interactions with groups of students working on the problem displayed in Figure 1 above, with the support of expert moderators. Members of the Drexel team will also collaborate with members of the Carnegie Mellon team on the analysis of the chat logs in order to identify strategies that the expert moderators modeled for this math problem. They will also conduct a systematic analysis of which VMT resources, such as the shared whiteboard and other graphical tools, were instrumental in effective student collaboration for this problem, since knowing this will allow us to determine which aspects of the VMT environment's capabilities are most important to integrate with the support agents in a deep way. At Carnegie Mellon University, the main work will be to design and build support agents based on the analysis they will conduct of the collected corpus collaboratively with the Drexel team using their existing technological foundation. They will also work on an initial integration of the support agents with the VMT environment and will work with the Drexel team on some trials with student teams working in the environment integrated with support agents.

6. Results from Prior NSF Funding

Rosé has supervised NSF EHR/SGER-0411483 (REC: Calculategy: Exploring the Impact of Tutorial Dialogue Strategy in Shaping Student Behavior in Effective Tutorial Dialogue for Calculus). This SGER project provided the foundational research on adaptive collaboration support that this proposal is built upon. This project began by exploring the idea of the instructional benefit of errors, which has its roots in Piaget's notion of *cognitive conflict* (Piaget, 1985). This cognitive conflict plays an important role in stimulating cognitive restructuring by making children aware of a deficiency in their current understanding for explaining the world around them. In a recent study (Gweon et al., 2005) we reexamined the effects of group composition on the functioning of collaborative learning dyads in the light of recent work on learning from incorrectly worked examples (Grosse and Renkl, submitted). In a follow-up study we explored the use of prompts to encourage more teaching oriented behavior from the student participants in light of results indicating that students benefit more from working with less capable peers when they engage in deep explanation activities (Gweon et al., 2006). This study demonstrated that adaptive support for collaboration increases teaching behavior and has a significant positive effect on student learning. Other publications from this work include foundational work for the subsequent TagHelper tools project (Gweon et al., 2005b), with subsequent work and downloadable toolkit at http://www.cs.cmu.edu/~cprose/TagHelper.html, and work on eliciting learning oriented behavior with dialogue agents (Rosé & Torrey, 2005).

Weimer and Stahl, who will be consultants on this SGER project, have jointly supervised the Virtual Math Teams (VMT) project at Drexel University. NSF DUE 0333493 Collaboration Services, $450,000, August 2003 to July 2005, NSF REC 0325447 Catalyzing & Nurturing Online Workgroups, $2,299,978, September 2003 to August 2008. Virtual Math Teams (VMT), led by Gerry Stahl, Drexel University, College of Information Science and Technology, Steve Weimar, Director of The Math Forum @ Drexel, and Wes Shumar, Associate Professor, Culture and Communication, Drexel University: The VMT Project investigates issues of online collaborative mathematics problem solving by extending the Math Forum's popular "problem of the week" service for use by small groups of students. These issues include the pedagogy of online collaborative learning of school mathematics, the design of appropriate software and the methodology of empirical research in such settings. See http://www.mathforum.org/vmt/researchers/orientation.html for more information as well as an extensive set of publications originating from this work.