CRACKING THE RESOURCE NUT WITH DISTRIBUTED PROBLEM-BASED LEARNING IN SECONDARY TEACHER EDUCATION

Constance A. Steinkuehler, Sharon J. Derry, Cindy E. Hmelo-Silver,

Matt DelMarcelle

Constance A. Steinkuehler, Research Assistant, University of Wisconsin-Madison, 1025 West Johnson Street, Madison WI 53706, steinkuehler@students.wisc.edu, T. 608.265.8530; Sharon J. Derry, Professor, University of Wisconsin-Madison, 1025 West Johnson Street, Madison WI 53706, SharonD@wcer.wisc.edu, T. 608.263.3676; Cindy E. Hmelo-Silver, Assistant Professor, Rutgers University, 10 Seminary Place New Brunswick NJ 08901-1183, chmelo@rci.rutgers.edu, T. 732.932.7496 x8311;

Matt DelMarcelle, Project Assistant, University of Wisconsin-Madison, 1025 West Johnson Street, Madison WI 53706, mdelmarcel@aol.com, T. 608.265.8530.

ABSTRACT

In this article, we focus on the features and functions of the STEP pbl System that enable us to support novice tutors and thereby address the human resource challenge that implementing a pbl course in a typical undergraduate setting poses. We describe the activities students in our course engage in and present preliminary findings from our first trial of the system. We then describe our strategies for distributing the functions of the tutor based on the first trial and previous course implementations. We conclude with a description of the research methodology we are using to shepherd our site development efforts.

Implementing problem-based learning (PBL) in a traditional undergraduate setting is really a problem of *resources*. At many universities, large undergraduate courses continue to be held in vast lecture halls typically equipped with an elevated stage in front and desks bolted to an inclined floor. In a good semester, there is one teaching assistant (TA) to roughly every 30 students. There are not enough *rooms* available during scheduled class time for uninterrupted small group work, not enough *computers* available to enable everyone to conduct research simultaneously, and not enough *time* in the typical undergraduate's schedule to allow groups to meet frequently and conveniently outside of class. In larger courses, TA's with minimal training often serve as tutors and, given the high turnover rate endemic to such positions, each semester the instructor, who may also have limited experience with PBL, contends with the prospect of starting over with a completely new staff. In smaller courses, a single roaming instructor struggles to distribute their time and attention across all groups equally, at once. If PBL is to effectively serve as the primary vehicle for learning in such undergraduate settings, the problem of resources must be addressed.

In the Spring of 2000, we redesigned how preservice teachers in our program engage with the Learning Sciences[1]. We took a traditional, lecture-style undergraduate course in educational psychology and restructured it into a PBL experience (pbl[2]) with the expectation that students who took our course would construct useful knowledge about the Learning Sciences to guide their subsequent instructional decisions and design. Ongoing analysis of data collected during implementation of the redesigned course indicates that our expectations about what students might gain through such activities were well founded; however, the pervasive resource challenges we, like others (Kirkwood, 1998), faced in accomplishing them raise the issue of sustainability (Derry & STEP Project Group, 2000). Despite the success of our curricular design, if we were to continue using pbl as the primary vehicle through which preservice teachers engage in the content of the domain, then we had to develop a solution to this pervasive problem of resource constraints.

Restructuring and distributing the pbl activities via the Web is a best-fit solution to the resource problem. By putting pbl activities online (www.wcer.wisc.edu/step), we are able to avert the physical and temporal constraints that previously served as potential barriers to our goals of continuing pbl instruction in our course and creating a viable national model for preservice teacher education. We can now provide students ample space (albeit virtual) for collaborative work, reduce the necessity to coordinate schedules, and give students greater freedom in choosing where they work from and when ("anytime/anywhere" interaction, Benbunan-Fich & Hiltz, 1999). Most importantly, however, our system enables us to address the *human resource* challenge — how do you implement pbl without a full staff of experienced tutors to facilitate students' collaborative work? Our strategy: *You distribute the tutor's functions across the system, the students and the staff.* Table 1 outlines our approach.

Place Table 1 about here.

In this article, we focus on the features and functions of the STEP pbl System which enable us to support TA's in their work as pbl tutors and thereby address the human resource challenge that implementing this type of course poses. First, we briefly outline the activities students in our course engage in and present preliminary findings from our first trial of the system. We then describe some of our strategies for distributing the functions of the tutor based on these data from the first trial, informal discussion with the tutor, and previous implementations of our course. We conclude this paper with a description of the research methodology we are using to shepherd our site development efforts.

OVERVIEW OF STUDENTS' ACTIVITIES

Students in our course learn to apply the Learning Sciences to teaching through collaborative problem solving that involves the study of videocases[3] of actual classroom instruction. Each videocase presents the story of a particular piece of instruction, either model instruction to be emulated and/or adapted (e.g., the successful use of cognitive modeling procedures) or popular instruction in need of redesign (e.g., the proverbial "chalk and talk" techniques). The problem students face is to adapt or redesign the instruction based on Learning Science research. In order to accomplish this, students conduct an individual preliminary analysis of the videocase and then meet with their pbl group online to share and negotiate their ideas, generate learning issues (Barrows, 1985), conduct research, and then reason through their preliminary ideas in light of what they investigate. Once the group work is completed, each student composes his or her own final solution proposal, compares it to an expert analysis[4], and then reflects back on the products and processes so generated (see Figure 1 for more detail). This process is supported by the Knowledge Web (STEP Project Group, 2000), a richly interlinked network of Learning Science concepts connected to each videocase (cf. Spiro, Feltovich, Jacobson & Coulson, 1991) and the Student Module, a series of interactive webpages and tools that scaffold students' through the pbl process[5].

Place Figure 1 about here.

These activities are designed to develop students' reasoning and problem solving skills in addition to content knowledge. Our goal is more than simply transmission of the latest findings in the Learning Sciences; our expectation is that students in our course will develop an ability to use current theory and research on cognition to guide instructional decisions and design. By situating instructional design and decision-making in the context of collaboration rather than isolated independent practice, our activities afford preservice teachers the opportunity to engage in sustained collaborative work of the type we want practicing teachers to engage in.

The nature of the problems in our pbl design reflects the unique nature of the profession of teaching. We incorporate both "ideal" and "not-so-ideal" instruction in our repertoire of problems so that preservice teachers taking our course are exposed not only to model instruction that illustrates ideals of reform — ideals that are *not* always well illustrated in the schools where our students observe and teach — but also to the kind of instructional problems they will likely face once they enter the field. In so doing, we aim to improve students' abilities to analyze classroom instruction (whether it be sound or shaky) on the basis of research and to then design instruction on the basis of such analyses.

RESULTS FROM FIRST TRIAL

Two groups of five preservice teachers, enrolled in an educational psychology course at a major eastern university, volunteered to participate in our first trial of the STEP pbl system at a distance. Students were presented a redesign problem containing a videocase story of a traditional, from-the-textbook, largely lecture-based instructional unit taught by a popular teacher in a Midwestern public high school science class. Though the instructor had taught the unit several times, the attending assessment materials indicated that students did not grasp the content. The challenge students faced was the following: "You are part of an online professional development community of which the teacher in the videocase is a member; he has asked your community for advice on how to improve his lesson. Advise him on how to proceed and justify your group's redesign proposal using Learning Science concepts." Students took approximately three weeks to complete the activities outlined in the previous section. One of the authors with extensive experience in pbl facilitation served as tutor for both groups.

Given that this was our first trial of the system beyond in-house user testing, our primary interest was to get an overall picture of the feasibility of our system design and to solicit suggestions from an expert tutor for functions and resources we might include in our system to scaffold and enhance the tutoring process online. More in-depth analysis will be presented elsewhere; here, we present students ratings of and comments on the system. Throughout the remainder of the paper, we outline the strategies (including system features, tools, materials and resources) we are developing to scaffold tutor performance, based on conversations with the tutor, previous implementations of our course, and extensive online journal notes the tutor kept throughout the trial.

Place Figure 2 about here.

Student ratings of various features of the system (Figure 2), collected at the end of the pbl activities, were positive in regard to the nature of the activity and constructive in terms of the technical design. At the time of the first trial, much of our system was in its early "prototype" stage and we were in the process of dealing with various technical issues (i.e. insuring consistent access under low-bandwidth connections, integrating the security systems to reduce the number of passwords necessary from three to one) that were not yet resolved. Average group ratings ranged from 3.2 (with 3 "fair") to 4.4 (with 4 "good" and 5 "excellent") on a Likert scale of 1 to 5 with no significant differences between groups. Combined with an examination of what users actually did (and did not do) and comments made during and after the trial, however, these data did suggest specific modifications that could be made to improve overall usability; these changes are discussed below.

DISTRIBUTING THE TUTOR'S FUNCTIONS

In traditional pbl, tutors play an important role in determining what and how students learn throughout their activities. As illustrated in Table 1, tutors are responsible for monitoring the flow of each student's activities, playing a metacognitive function for the group by probing students knowledge and reasoning, monitoring both interpersonal (e.g., the distribution of participation) and intrapersonal (e.g., the level of engagement of each individual student) dynamics of each group, and making educational diagnoses in terms of both product (knowledge) and process (critical thinking). Accomplishing these responsibilities is a challenge for the most seasoned tutors; for new TA's with little training and no experience teaching in a pbl context, it is a tall order indeed.

The STEP pbl System we are developing is designed to provide TA's the assistance, scaffolding and support necessary for successfully tutoring multiple online groups at once. Our strategy for accomplishing this includes, on the one hand, partially distributing the tutor's responsibilities across the system and the students themselves and, on the other hand, providing tutors a set of online tools and resources that can scaffold their tutoring performance, as well as a working environment that affords "in situ" use of the tools.

Heading 2 Guiding students through the appropriate sequence of phases

In a face-to-face pbl setting, the *tutor* is responsible for regulating the sequence of all pbl activities; in our online course, the three-session design of the Student Module enables *individual students* to guide themselves through parts of the pbl activity. A sequence of interactive webpages steers each student through two of three sessions of activities: "Session One: Individual Pre-Analysis," in which students explicate their initial situation model (Derry, 1996) of the videocase using the "Individual Whiteboard" (see Figure 1); and "Session Three: Individual Final Analysis & Reflection," in which students write their individual final solution proposals to the problem, compare and contrast their arguments with an expert's, and reflect back on their work. The central session, "Session Two: Group Investigation," is where the tutor facilitates group work, guiding each group of students through a collaborative process designed to help students use Learning Science concepts to construct a group situation model and *reconstruct* their individual situation models (from Session One), based on what they discover through investigation and online discussion with their peers.

A bank of online tools and resources scaffolds *tutors* as they, in turn, scaffold the *students* through the collaborative process. This bank of online resources outlines a suggested sequence of group activities based on what has worked in the past; each activity listed is linked to additional information regarding the purpose of the given activity, an elaboration of what the activity entails, and tips for when (and when *not*) to step in. Accessed via the Tutor

Module — a "digital dashboard" of sorts through which the tutor accesses and interacts with the students and the system — this bank of resources provides novice tutors practical strategies for how to guide students' collaborative work "from the side" without being intrusive, a challenge for TA's who are accustomed to a more directive instructional role.

Previously, the outline of students' collaborative activities was available only to tutors because we wanted to avoid over proceduralizing the group process. During the first trial, however, both student and tutor comments indicated that more explicit explanations were required. Students expressed confusion about the activities and their purpose. For example, one student expressed confusion regarding the purpose of starting with their own ideas rather than searching for the "right" answer in the research: "I don't feel its right to post something on the whiteboard until we get some really, core research done... until then, I can't say anything, but my opinion." (Karen Group 2.) In the words of the tutor, greater structure was called for:

> I am still frustrated with the parallel play aspect of the activity [Group 2's tendency to work independently in parallel rather than collaborate]. I think that first few times students do a problem like this they will need a lot of structure in the task, in terms of milestones and required numbers of notes in which part of the site. (Tutor, Online Tutor Journal).

In response, we are now creating more concrete Session Two explanations and suggestions for the students that will mirror the descriptions provided to the tutor in the Tutor Module and developing a system that will enable tutors to set explicit posting requirements, expected group milestones, and deadlines for accomplishing them. Once these criteria are set by the tutor, the information will be automatically relayed to the students via the Student Module interface. Although this may seem paradoxical since pbl is a student-centered approach, we expect that communicating the structure and expectations more clearly to students in the beginning will afford them greater autonomy in the long run; once students become familiar with the general procedures, they can make their own informed decisions on how to structure their group activities and these scaffolds can be faded.

Heading 2

Insuring adequate attention to each phase

The three-session design of the pbl activity does more than structure students through activities; it also insures that students pay adequate attention to the preliminary and follow-up phases contained therein. By dynamically tracing what each student has completed and then providing access to the next activity or session in the series based on this trace, the Student Module monitors students' progress by limiting forward access based on adequate completion of prior tasks. By placing students' collaborative work between two other sessions of individual activities, we are able to ensure both adequate preparation prior to discussion and adequate reflection and follow-up by individuals after the collaboration has occurred. Session One, which precedes discussion, orients students to the kind of "mindset" pbl activities require, familiarizes them with the overall learning objectives and how each activity helps them meet those objectives, and engages them in thinking deeply about the problem before discussing it with their peers. Session Three, completed after the discussion, ensures adequate follow-up on what was learned individually, providing each student the opportunity to articulate his or her own *individual* final solution to the problem — a key product for assessment purposes, since teacher certification is based on individual, not group, performance — and then reflect back on how his or her initial ideas changed by investigating Learning Sciences concepts and discussing their importance for instructional design.

Placing the students' collaborative work between two individual sessions enable us to distribute the scaffolding functions for which tutors are traditionally responsible, not just over the system, but over the students as well. Adequately preparing individual group members prior to group discussions enables them to monitor their own progress, in terms of both content and process, *in collaboration with* the tutor once the group work begins. By orienting each member to the "mindset" and basic structure of pbl, groups can take responsibility for their own facilitation to some extent, given preliminary assistance from the system (Session One) and a monitoring TA (overseeing several groups). The system modifications described above should facilitate this process; by clearly communicating the specific milestones each group is expected to accomplish and their deadlines, students can be held accountable for their own progress.

Heading 2

Encouraging students' to make their knowledge & reasoning public

During their collaborative work, students make their knowledge and reasoning public through a combination of an asynchronous discussion *environment* and strategically designed online "Group Whiteboard," which structures the group *product*. Group members share and negotiate their pre-analysis ideas on the online threaded discussion board and then post their consensual results to the Group Whiteboard (see Figure 1). Assuming that students comply with the pbl injunction that "silence is assent," the text-based nature of these two collaborative spaces translates each student's reasoning about the discussed issues into public document.

By moving the group's negotiation from a synchronous face-to-face environment to an asynchronous online one, we are able to transform the discussion from a temporal unfolding of talk to a cascade of inscriptions that, quite literally, "artifacts" the developmental trajectory of each discussion topic over time (cf. Bailey & Luetkehans, 1998). Threaded discussions offer distinct advantages over synchronous ones, fostering more serious and lengthy interactions (Bonk, Hansen, Grabner-Hagen, Lazar, & Mirabelli, 1998), more reflective responses (Davidson-Shivers, Tanner & Muilenburg, 2000), increased group interaction (Eastmond, 1992), and more equitable communication patterns (Harasim, 1990). Comparisons to face-to-face show no differences in terms of relational communication (Walther & Burgoon, 1992), group cohesiveness, or quality of group products (Burke & Chidambaram, 1995). In fact, asynchronous discussion has been shown to actually *enhance* the quantity and quality of the solutions in case based instruction (Benbunan-Fich & Hiltz, 1999).

This is *not* to say, however, that threaded discussion is a panacea for collaborative work. Used alone, the hierarchical organization inherent in such tools can obscure the main thrust and development of the group's reasoning rather than elucidate it, making consensus hard to reach (Hiltz, Johnson, & Turoff, 1986). Because new posts are added sequentially over time, the content of each thread can become more and more diffuse, leading to "a sense of information overload and confusion about the intellectual focus of the community" (Hewitt, 1997). In order to prevent this outcome, we combine such discussion with a shared workspace for recording the group's consensus argument, the Group Whiteboard.

In essence, the Group Whiteboard is a more elaborated version of the two columns of the Individual Whiteboard students completed individually during Session One (i.e., "what should be done" and "why it should be done"). Using this shared tool, each group records their consensus solution ideas and how the results of their pooled research into the Learning Sciences bear on each idea. By providing the group space in which to cite both confirming and disconfirming evidence (for a classic discussion of "confirmation bias," see Wason & Johnson-Laird, 1972) as well as the source of their claims, this tool enables students to literally see how and where the Learning Science concepts they investigate bear on their solution ideas. In this manner, the Group Whiteboard makes the group thinking visible for members and the tutor alike.

Based on the first trial, however, we cannot yet determine whether this combination of threaded discussion and online Group Whiteboard has the cognitive affordances we, in theory, predict. Unanticipated complications arose during students' Session Two activities that resulted from simple design flaws. Students didn't know which tool was for which purpose: "Are we supposed to be talking here and putting our research there or the other way around? I am sorry but I am quite confused" (Karen, Group 2). As a result, they did not use the two spaces as we intended; rather than deliberating in the discussion space and then posting the results to the group product, participants treated both spaces as identical, conducting discussions and posting proposals in both. As a result, the two spaces coalesced in unproductive ways — on the one hand, bifurcating topical conversations as they developed; on the other, eliminating the ability for groups to develop a distinct product representing the fruits of their labor for all to see.

This amalgamation of the two collaborative spaces appears to have resulted from a basic design flaw: the Session Two interface, as designed and implemented during the first trial, made the Group Whiteboard more salient than the discussion space, with the former embedded *within* the interface and the latter located in an *external*, second window. Our directions did not distinguish between the purposes of the two spaces sufficiently and students simply used the first space they encountered to collaborate as instructed. Toward solving this, we have now built a new threaded discussion tool, integrated directly into the Student Module interface, that better coordinates with the Group Whiteboard and have clarified our directions for using both tools. We suspend judgment on this design until our next trial.

Heading 2 Probing students' knowledge & reasoning.

Video data collected from the Spring 2000 implementation of our course indicates that, in face-to-face pbl, probing students' knowledge and reasoning "on the fly" places considerable burden on a novice tutor (Derry, Seymour, Feltovich, & Fassnacht, 2001). In the online environment, our combination of asynchronous discussion and Group Whiteboard plays a critical role in scaffolding tutors in serving a metacognitive function for each group and distributing such regulatory processes across the group members as well. The discussion space transforms student deliberations into a cascade of inscriptions that can be perused, reviewed, and considered in context, enabling both the tutor and the students to take a more reflective stance toward each individual posting and the trajectory of the group work as a whole. In addition, the Group Whiteboard enables students to literally see how and where the Learning Science concepts they investigate bear on their solution ideas, thereby increasing their own metacognitive awareness of what they are learning and whether/how it prompts revision of their initial beliefs about teaching, learning and instructional design.

In metacognitive terms, the Group Whiteboard is vital; it structures not only the *group product* but the *group process* as well (cf. Suthers, 1999). First, it makes the constituent elements of the group argument (i.e., claims, pros and cons, evidence) salient and therefore more likely to be attended to, negotiated and elaborated upon. Second, it makes the relationships between these elements explicit, providing a framework within which group members can negotiate the import of the results of their investigation. Finally, it makes the gaps or absences within the argument conspicuous, hence a topic for discussion in their own right. Individuals within the group must organize their activities via reference to the group product; as a result, both individual and group activities get coordinated by the Group Whiteboard structure we carefully designed. In this manner, the Group Whiteboard fosters metacognition; it makes the line of reasoning inherent in the group argument explicit, hence a topic for consideration in its own right.

Are these structural features sufficient? Probably not. Pbl, in its best moments, is a form of cognitive apprenticeship (Collins, Brown, & Newman, 1989) in which the tutor explicitly displays the otherwise tacit cognitive strategies used by experts in the domain. As Hmelo and Guzdial (1996) argue, one of the key roles of the tutor is to model the thought processes and kinds of questions in which students should engage. Questioning strategies are first demonstrated by the tutor and then progressively faded as students internalize and use them on their own. How, then, does our online system support tutors in this process?

Our strategy is to provide model questions to the tutors. The bank of tutoring resources described earlier provides example expert "conversational moves" that the tutor can use to probe students' knowledge and reasoning. These materials provide tutors tangible ways to guide the group discussion in conjunction with information about the purpose of each so that they themselves can decide which "moves" to make and when. We found that many of the postings the expert tutor made to both Group 1 and Group 2 during the first trial were similar if not identical. Based on these turns, we've created example postings for each activity phase. Conversational moves such as "Lots of good ideas in here – how do you think that he might get at students prior knowledge of static electricity? What do you mean by information overload?" or "That's an interesting idea. Why do you think that? Is there any evidence that supports it?" or "Does everybody agree with this definition of constructivism?" can be copy-and-pasted into the discussion board or edited at will. Eventually group members internalize these conversational strategies and the tutor's scaffolding can be reduced, but by giving tutors a set of explicit, example expert questions that have been productive for group thinking in the past, we hope to provide support that less experienced staff members can lean on.

Heading 2

Insuring equitable participation and interaction

Technologies "do not simply cross space and time; they also can cross hierarchical and departmental barriers" (Sproull and Kiesler, 1991, p. ix). For this to happen in collaborative settings, however, you must insure equitable participation and interaction among all group members. Orchestrating each online asynchronous discussion in order to insure all voices are heard is difficult; tutors in our course monitor several groups simultaneously, making accurate diagnosis of the patterns of interaction difficult. In order to assist, we are developing a diagnostic tool, accessible via the Tutor Module: an "Interaction Matrix."

An Interaction Matrix representing the distribution of discussion board postings within each group provides the tutor a snapshot of the level of engagement (i.e., who has/has not posted, how many postings have been made, and by whom) and its "center of gravity" (for a simple overview to this method, see Wortham, 1999). Our current thinking is that each participant in the discussion will be represented as a vector containing the number of replies he or she has made to every other participant, yielding a matrix representation of the interaction occurring within the group. Unequal interaction, such as one person's postings receiving the majority of the responses, is designated by higher numbers within the matrix. Information gleaned from the student profile—biographical information each student enters at first login such as major, gender, year in school, native language, etc. — is used to highlight potential sources of within-group status differences, enabling the tutor to see whether the distribution of talk divides along status lines. Using this tool, the tutor can better monitor the interpersonal dynamics within the group to insure group responsibility and equal participation of all members and, when necessary, to promote reflection on group process when issues arise.

Heading 2 Promoting reflection on collaborative learning and group process.

The sole function of the third and final session of the Student Module is to help students come to understand how their own argument about teaching, learning, and instructional redesign has been revised as a result of their group work. During this session, students are asked to reflect on the products and processes resulting from their online collaboration, including the extent to which the discussion led them to elaborate and revise their initial ideas. But while our original design included a tool for helping individuals reflect on their learning from the group, it did not include a *group* reflection tool that might guide students through joint reflection on the group's communal work.

Our current revisions are correcting this: examination of students' activities during the first trial revealed that an excellent opportunity for learning had been missed. Peer evaluation of the group collaborative process is critical if students are to improve their own collaborative and negotiation skills over time. Toward this end, we are now developing a group feedback form that both group members and the tutor can complete at the end of their collaboration and then post to the discussion board. Using this form, each individual will be able to provide constructive comments on their fellow group members, the tutor, and their own contributions to the group work.

Heading 2 <u>Assisting students' self-directed study</u>.

The <u>Student Module</u> provides students access to Learning Science content materials contained in the <u>Knowledge Web</u> (STEP Project Group, 2000), a network of densely interlinked concept pages linked to each videocase. Findings from the first trial indicate that students who made use of this resource found it extremely useful; however, we underestimated the slope of the learning curve required to acclimate to the site's navigational complexity. Some students simply struggled, feeling overwhelmed and lost in space:

> Next time, I would use the Knowledge Web more. I had trouble using it and…got frustrated and reverted to other sources. I would use it a lot more as other people in my group found it very useful. (Connie, Group 2)

Although such problems are partly an issue of improving Knowledge Web navigation, tutors must be able to aid students who are struggling with their self-directed investigation. In the STEP pbl system, a "Use of Resources" report tool in the Tutor Module provides the tutor a quick snapshot of how group members are faring in their online research. Our system's ability to provide a "trace" of each student's online activities is now being extended into the Knowledge Web. By recording the pages each student accesses in sequence and then preprocessing this list in terms of each page's "number of links" distance from the assigned videocase, we can provide the tutor access to reports on whether group members successfully accessed content materials, their strategies for research, the depth and breadth of the group's investigation, and whether critical concepts for the case or specific resource suggestions were found. Such information can provide the tutor, should they need it, a general sense of how students are faring during their investigation through an admittedly complex hypertext space.

Heading 2 Making educational diagnoses

Finally, and most importantly, we are designing a system that enables the instructional staff (tutors and the supervising course instructor) to assess both individual and group *conceptual change*. If we take student learning via online collaboration seriously, then to some extent we must measure the degree to which it prompts individual conceptual change. If students complete their group work with the same understanding of cognition and instruction that they originally brought to the activity, then the collaborative learning activity, on some level, failed; we may have engaged students in joint problem solving, but we failed to engage them in significant belief revision, which (as we've hopefully made clear by now) is one of our course's primary goals. In order to measure, then, the extent to which the collaborative activities are productive learning mechanisms as we intend, we must capture the evolution of individual cognition over time (Derry & Hmelo, 2001).

The Group Whiteboard documents the evolution of the group's shared thinking by making visible (to students as well as the tutor) change in the group's argument over time; the real challenge, however, is documenting the cognitive development of each participating member. Our strategic three-session design enables us to document such change. Over the course of the three sessions of activities, students generate a cascade of inscriptions that capture their current thinking about the problem, the Learning Science concepts, and the relationships among them. This individual trace includes (a) the Individual Whiteboard competed during Session One, (b) the individual's contributions to the discussion board and Group Whiteboard completed during Session Two; and (c) their final solution proposal completed during Session Three. Together, these inscriptions provide a trace of the evolution of the individual's thinking over the course of their pbl activities. Examination of this trace allows staff, researchers and students themselves to assess what conceptual change took place at the individual level as a result of the discussion and we are currently considering methods such as latent semantic analysis (Landauer, Foltz & Laham, 1998) for reducing and processing these data for easier interpretation. Whether and what nature of individual cognitive development occurs is an important measure of the potency of the given online collaboration as a learning activity in itself.

ACCUMULATING & DISTRIBUTING WISDOM & PRACTICE

One of the beauties of online systems is their capacity to generate an ever-thickening history of use. In this article, we have tried to show how preliminary analysis of the data from our first trial of the system has helped us identify tutor needs and implement a suite of online materials and tools to scaffold and assist novice tutors. With every such trial on our system, we gain one more layer of description: what the students and tutors did and whether it was successful, the kinds of problems they encountered and the ways they moved beyond those challenges, unanticipated issues that arose…and this does not include the yet-to-be-harvested data from the first trial that we have not explored. For better or worse, our monitoring and assessment systems seem to database *everything*, from Jane Doe's connection speed to whether Group Q took Labor Day weekend off. The trick is: *putting all these data in the service of future research and practice.*

Our site development strategy is very simple: *accumulate wisdom and practical skill through repeated trials and then distribute it across resources, tools, and artifacts.*

The online resources we are building are artifacts of our own accumulated wisdom; they provide "newcomers" (Lave 1991), whether they are students or staff, access to the experiential knowledge our team has developed over time. This article is full of examples, yet there are others we simply haven't the space to detail: worked examples of each "product" for the students, a register of frequent misconceptions students bring to each problem and the common difficulties students have had while working with various cases in the past, and a collection of problem-specific research suggestions that tutors can share with students who get stuck. These resources represent the accretion of practical knowledge and skill over time; using the rich "trace" of student and staff activities that our database generates in combination with tools such as the online "Tutor Journal" where tutors record their observations on each group, we transform system use into system knowledge, thereby sharing experiences and growing wisdom with future staff. By providing a way for each tutor to archive their current experiences, reactions, and suggestions, we are able to continue building tutor wisdom into the system and provide an ever-thickening history of each problem for future tutors to consult.

> I am glad to have the journal linked here. I hope that my armchair quick view of the students is helpful and provides some context for understanding these folks as individuals situated in my pbl ed. psych. class. (Tutor, Online Tutor Journal)

CONCLUDING COMMENTS

Perhaps this paper might better be entitled "problem-based *designing* in secondary teacher education." Our work on STEP pbl System is motivated by a real-world problem we have encountered in our research: How do you implement a pbl-based course in an undergraduate setting with limited tutor training capabilities and a meager instructional staff? Our strategy, broadly stated, is to carefully design a set of resources and tools that enable us to distribute the complex cognitive and pedagogical processing that tutoring pbl requires to the system, the course staff, and the students (both individually and in groups). Working out precisely how to accomplish this will require repeated design cycles of prototyping, testing, and revising our initial ideas. Throughout this process, there will be glitches, snags and (technological) hurdles, as this article demonstrates, yet the objective that motivates such trials and tribulations — developing preservice teachers' ability to use current Learning Sciences research to guide instructional decisions and design — are already partially realized.

> One of my students accidentally showed up at class today-- a student who had great difficulty getting on. He stayed up most of the night finishing up and said that he really liked doing this online-- he said that it is one of the hardest things he's ever done but one of the best, that he felt like he learned an awful lot, despite assorted technical problems (like losing what he had been working on in the whiteboards when he moved to the knowledge web). So for what this is worth, at least one student

who had a very difficult time figuring out what to do found this a really worthwhile experience. (Tutor, Online Tutor Journal)

ACKNOWLEDGEMENTS

This work was supported by the National Institute for Science Education, a cooperative agreement between the National Science Foundation and the University of Wisconsin-Madison, and by a grant from the Joyce Foundation. Sharon J. Derry is principal investigator. The ideas expressed herein are not endorsed by and may not be representative of positions endorsed by the sponsoring agencies. The authors are grateful to David Woods, Chris Fassnacht and Marcelle Siegel for their helpful comments on the design of our system and useful feedback on earlier versions of this paper.

NOTES

[1] We use the term "Learning Sciences" to refer to all fields of systematic, empirical study of cognition and education, including work conducted from the full range of theoretical perspectives from Symbolic Processing Theory to Situated Cognition and Sociocultural Theory.

[2] We use "PBL" to refer to the Problem-Based Learning technique originally designed by Barrows (1985); we use "pbl" (all lowercase letters) to refer to the modified version of problem-based learning used by STEP. We maintain this distinction throughout our work in order to acknowledge the fact that we employ online *asynchronous* discussions while Cameron, Barrows & Crooks (1999) specify that such discussions should always occur synchronously. Our use of

asynchronous rather than synchronous environments was a deliberate design decision; the rationale behind this decision is discussed later in the paper.

[3] Videocases are the centerpiece of the STEP system. Each videocase includes not only the video footage itself but also a written transcript of its contents and a collection of supplementary "Inquiry Materials" that provide a richer picture of its context (e.g. demographic information, interviews with the teacher, examples of student work, item analysis of assessments).

[4] Our system will eventually incorporate several different "expert analyses" for each videocase. We feel that multiple expert analyses would better represent the range of theoretical perspectives one might productively take in thinking about cognition and instruction. There is no single correct to solution to any of the problems we use in our course; our bank of expert analyses will reflect this.

[5] Students' pbl activities vary depending on problem type (i.e. whether they are redesigning or adapting the instruction depicted in the videocase), therefore the interactive webpages and tools that scaffold students' through them correspondingly vary. For ease of presentation, however, we focus this discussion on the system that supports students' *redesign* activities.

REFERENCES

Bailey, M. L. & Luetkehans, L. 1998, Ten great tips for facilitating virtual learning teams, paper presented at the Fourteenth Annual Conference on Distance Teaching & Learning.

Barrows, H. S. 1985, *How to design a problem-based curriculum for the preclinical years*, Springer, New York.

Benbunan-Fich, R. & Hiltz, S. R. 1999, 'Impacts of asynchronous learning networks on individual and group problem solving: A field experiment', *Group Decision and Negotiation*, vol. 8, no. 5, pp. 409-426.

Bonk, C. J., Hansen, E. J., Grabner-Hagen, M. M., Lazar, S. A. & Mirabelli, C. 1998, 'Time to 'connect': synchronous and asynchronous dialogue among preservice teachers', *Electronic collaborators: Learner-centered technologies for literacy, apprenticeship, and discourse*, Erlbaum, Mahwah NJ, pp. 289-314.

Burke, K. & Chidambaram, L. 1995, 'Developmental differences between distributed and face-to-face groups in electronically supported meeting environments: An exploratory investigation', *Group Decision and Negotiation*, vol. 4, no. 3, pp. 213-233.

Cameron, T., Barrows, H. S. & Crooks, S. M. 1999, Distributed problem-based learning at Southern Illinois University School of Medicine, paper presented at the Third Annual International Conference for Computer Supported Collaborative Learning.

Collins, A., Brown, J. S., & Newman, S. E. 1989, 'Cognitive apprenticeship: teaching the crafts of reading, writing, and mathematics', *Knowing, learning, and instruction: Essays in honor of Robert Glaser,* Erlbaum, Hillsdale NJ, pp. 453-494.

Davidson-Shivers, G., Tanner, E. Muilenburg, L. 2000, 'Online discussion: how do students participate?, paper presented at the Annual Meeting of the American Educational Research Association.

Derry, S. J. 1996, 'Cognitive schema theory in the constructivist debate', *Educational Psychologist*, vol. 31, no. 3/4, pp. 164-174.

Derry, S. J. & the STEP Project Group* 2000, Reconceptualizing professional development: Collaborative video projects on the world-wide web, paper presented at the Annual Meeting of the American Educational Research Association. (*Kim, J. B., Steinkuehler, C. A., Siegel, M., Street, J. P., Canty, N. G., Fassnacht, C., Hewson, K., Hmelo, C. E. & Spiro, R.)

Derry, S. J., Seymour, J., Feltovich, P., & Fassnacht, C. 2001, Tutoring and knowledge construction during problem-based learning: An interaction analysis, paper presented at the Annual Conference of the National Association for Research in Science Teaching.

Derry, S. J. & Hmelo, C. E. 2000, Video cases online: cognitive studies of preservice teacher learning, proposal to the National Science Foundation's Research on Learning and Education (ROLE) Program.

Eastmond, D. V. 1992, 'Adult distance study through computer conferencing', *Distance Education*, vol. 15, no. 1, pp. 128-152.

Harasim, L. 1990, 'Online education: An environment for collaboration and intellectual amplification', *Online education: perspectives on a new environment,* Praeger Publishers, New York, pp. 39-64.

Hewitt, J. 1997, Beyond threaded discourse, paper presented at the Annual WebNet Conference.

Hiltz, S. R. 1986, 'The 'virtual classroom.' Using computer-mediated communication for university teaching', *Journal of Communication*, vol. 36, no. 2, pp. 96-104.

Hiltz, S. R., Johnson, K. & Turoff, M. 1986, 'Experiments in group decision making: Communication process and outcome in face-to-face versus computerized conferences', *Human Communication Research*, vol. 13, no. 2, pp. 225-252.

Hmelo, C. E., & Guzdial, M. 1996, 'Of black and glass boxes: scaffolding for learning and doing', *Proceedings of the First International Conference of the Learning Sciences,* AACE, Charlottesville VA, pp. 128-134.

Kirkwood, A. 1998, 'New media mania: Can information and communication technologies enhance the quality of open and distance learning?', *Distance Education - An International Journal*, vol. 19, no. 2, pp. 228 — 241.

Landauer, T. K., Foltz, P. W., & Laham, D. 1998, 'Introduction to latent semantic analysis', *Discourse Processes*, vol. 25, pp. 259-284.

Lave, J.1991, 'Situating learning in communities of practice', *Perspectives on socially shared cognition*, American Psychological Association, Washington DC, pp. 63-82.

Spiro, R. J., Feltovich, P. J. Jacobson, M. J. & Coulson, R. L. 1991, 'Cognitive flexibility, constructivism, and hypertext: random access instruction for advanced knowledge acquisition in ill-structured domains', *Educational Technology*, vol. 31, no. 5, pp. 24-33.

Sproull, L. & Kiesler, S. 1991, *Connections: new ways of working in the networked organization*, MIT Press, Cambridge MA.

The STEP Project Group* 2000, 'Promoting teachers' flexible use of the learning sciences through case-based problem solving on the WWW: a theoretical design approach', *Proceedings of the Fourth International Conference of the Learning Sciences,* Erlbaum, Mahwah NJ, pp. 273-279. (*Siegel, M., Derry, S. J., Kim, J.,-B. Steinkuehler, C. A., Street, J., Canty, N., Fassnacht, C., Hewson, K., Hmelo, C. E., & Spiro, R.).

Suthers, D. 1999, 'Representational support for collaborative inquiry', *Proceedings of the 32nd Hawaii International Conference on the System Sciences (HICSS-32),* Institute of Electrical and Electronics Engineers, Inc. (IEEE).

Wason, P. C. & Johnson-Laird, P. N. 1972, *Psychology of reasoning: Structure and content*, Harvard University Press, Cambridge MA.

Walther, J. B. & Burgoon, J. K. 1992, 'Relational communication in computer-mediated interaction', *Human Communication Research*. vol. 19, no. 1, pp. 50-88.

Wortham, D. 1999, Nodal and matrix analyses of communication patterns in small groups, paper presented at the Third Annual International Conference for Computer Supported Collaborative Learning.

Table 1. Distribution of the tutor's functions across modules within the STEP pbl system, students and staff

Tutor's Functions*	Online System: Student Module	Online System: Discussion Environment & Tools	Online System: Tutor Module	Tutoring TA	Students: Individual	Students: Group
To guide students through an appropriate sequence of phases	√		√	√	√	
To insure adequate attention to each phase	√			√	√	√
To serve a metacognitive function for the group						
To encourage students to make their knowledge & reasoning public		√				√
To probe students' knowledge & reasoning		√	√	√		√
To monitor the interpersonal dynamics						
To insure equitable participation & interaction			√	√		√
To promote reflection on group process	√				√	
To monitor the intrapersonal dynamics						
To assist students' self-directed study when necessary	√		√	√	√	
To encourage reflection on process & products	√				√	
To make educational diagnoses	√	√		√	√	

* This list of tutor's functions is adapted from "Facilitating the group process," a resource designed for PBL tutors by the Department of Medical Education, Southern Illinois University (1997). These regulatory functions are modeled and then gradually relinquished to the students themselves as their familiarity and competence with the pbl process increases.

Figure 1. Outline of students' activities in the STEP pbl System.

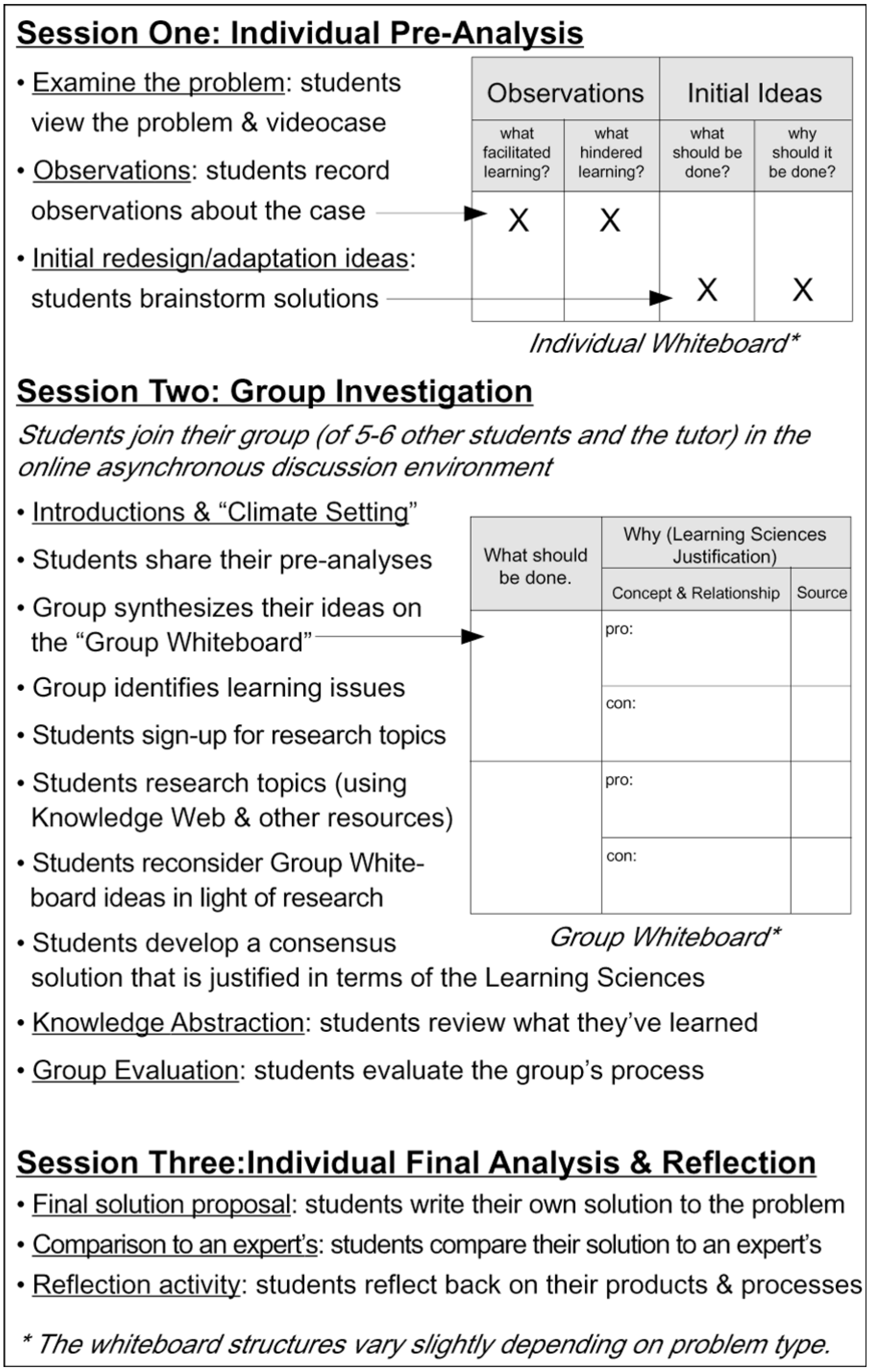

Figure 2. Mean Likert scale responses (from 1 min — 5 max) to pbl System feedback survey.