Facilitating Collaborative Knowledge Construction

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Abstract

This paper will describe a detailed analysis of a problem-based learning group to understand how an expert facilitator supports collaborative knowledge construction. The study examines the questions and statements that students and the facilitator generated as they traversed a complex conceptual space. The facilitator tended to use open-ended metacognitive questioning and never offered new ideas. His contributions built on the students thinking. These moves helped support deep student engagement with conceptual knowledge. Several specific strategies were identified that supported the goals of helping students construct causal explanations, reason effectively, and become self-directed learners. Studying facilitation in a face-to-face situation provides some guidance in designing support to use in an online problem-based learning environment; however, considerable adaptation is necessary as some facilitation can be built into the system but other facilitation may need to be done by a human tutor. Implications for CSCL system design for problem-based learning as well as preliminary experience with an online PBL system is discussed.

1. Introduction

From a constructivist perspective, discourse is a central mechanism for learning [1]. Orchestrating constructive discourse is a complex process whether in a classroom or online [2]. How one teaches and the strategies that are applied are intimately related to a teacher's beliefs about the nature of the teaching-learning process [3]. Teachers must juggle many simultaneous goals as they coordinate pedagogical actions with semantic knowledge. For experts, teaching is a problem-solving context in which they must come to understand the meaning of students' ideas rather than just correct them [4]. This is especially true when the teachers and students co-construct the instructional agenda in a student-centered classroom. In this paper, I will present a study of a master facilitator in a specific student-centered learning environment, problem-based learning (PBL) to identify the tactics and strategies that characterize the teacher's role in guiding student learning and examining how students collaboratively construct knowledge. This is accomplished through an analysis of the facilitator's role in the tutorial discourse, specifically the nature of the questions and statements that were made as students moved through the conceptual space. PBL is an instructional method in which students learn through solving problems and reflecting on their experiences [5]. In this approach, the teacher's role is to facilitate collaborative knowledge construction.

There are many cognitive activities involved in teaching and different discourse strategies to actively engage students. Schoenfeld [3] examined how some of these strategies through detailed analyses of expert and novice teachers. The novice teacher used a teacher-centered approach, initiating known-answer questions, the students responded, and the teacher evaluated the response., the IRE pattern found in many classrooms in which the teacher asks 95% of the questions, mostly requiring short answers [6]. Thus many teachers' goals often focus on having students learn facts. Even in one-on-one tutoring, the tutor asks 80% of the questions [7]. In contrast, inquiry teachers have goals that include having students learn the facts but go to higher levels of learning as well. A study of inquiry teachers identified several different types of goals and strategies that are used [8]. They found that inquiry teachers' goals encompassed having students learn theories and how they are derived. This included having students learn what questions to ask, how to make predictions, and how to test theories. Their analyses showed that these teachers use a variety of strategies to achieve these goals. Inquiry teachers used questioning techniques to promote deep thinking. In inquiry teaching, students are more active than in IRE discourse but the teacher still leads the discussion, working towards global goals but choosing strategies on the fly.

Schoenfeld found similar results in analyses of other inquiry teachers [3]. For example, one teacher used questioning in very productive ways to guide student thinking. He often used a technique called the reflective toss, in which the teacher catches the meaning of a student statement and throws responsibility for elaboration back to the student. He used these statements to help students clarify meaning, consider a variety of views, and to monitor their own thinking.

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This goes beyond Collins and Stevens [8] description of inquiry teaching by helping students become aware of their own thinking.

One key to creating an environment that supports collaborative knowledge construction is to provide opportunities for constructive discourse. Research on tutoring is informative for examining effective learning discourse. Good tutors, like good teachers, provide learning opportunities for students and not just explanations [6, 9]. Tutors do not often provide long explanations based on sophisticated diagnoses of student errors or detailed models of student understanding [7, 9]. If tutors do not actually provide much explanation or sophisticated diagnosis, then there must be an alternative explanation for the effectiveness of tutoring. Chi et al. [9] conducted a study in which some tutors were allowed to use their natural tutoring strategies but others were restricted to using content-free prompts and were not permitted to provide explanations and feedback. The prompted students outperformed the students who received normal tutoring on deep inference questions. The researchers concluded that the effects of tutoring occur because the tutoring interaction provides opportunities for constructive activity by he students [9]. Whether in a classroom, a tutoring situation, or an online interaction, there must be discourse structures that provide opportunities for knowledge construction [10].

PBL is widely used in medical schools [11, 12]). PBL is an example of a cognitive apprenticeship [13]. In a cognitive apprenticeship, students learn in the context of solving complex, meaningful tasks. The facilitator must make key aspects of expertise visible and make tacit thought processes explicit. Students work on problems in small groups guided by a facilitator. The facilitator guides students in the learning process, pushing them to think deeply, and modeling the kinds of questions that students should be asking themselves. The facilitator also monitors group dynamics and keeps the learning process moving. Collaborative groups provide a forum for students to distribute the cognitive load and negotiate shared understanding as they solve the problem.

A typical PBL tutorial session begins by presenting a group, typically 5-7 students with a small amount of information about a complex problem [12, 14]. Students inquire to obtain additional information from the problem materials (for example, the medical students have a paper simulation with the results of hundreds of history questions, physical examinations, and laboratory tests). Periodically, the facilitator will guide the students to reflect on the data they have collected so far, generate questions about that data, and ideas about solutions. Students identify concepts they need to learn more about to solve the problem. These are called learning issues. After considering the case with their prior knowledge, the students divide up and independently research the learning issues. They then regroup to share what they learned, and revisit their initial ideas in light of their new knowledge. After completing the task, they reflect on the problem to abstract the lessons learned and how they performed in their learning and collaborative problem solving. This important step helps prepare the students for transfer [15].

While working, students use whiteboards to help scaffold their problem solving. The whiteboard is divided into four columns to help them represent where they have been and where they are going. The columns also help remind the learners of the problem-solving process. The whiteboard serve as a focus for group deliberations. The *Facts* column holds information that the students obtained from the problem statement. The *Ideas* column serves to keep track of their evolving hypotheses. The students place their questions for further study into the *Learning Issues* column. They use the *Action Plan* column to keep track of plans for resolving the problem.

Social constructivist approaches to learning drastically change the roles of the student and teacher. The students drive the discussion and the teacher serves as the guide on the side [1]. This makes the role of teacher no less important but it is different from their role in direct instruction. Understanding how an expert facilitates productive learning discourse in terms of the goals, strategies, and tactics that he uses has important implications for training new facilitators and in designing CSCL systems. Examining group discourse in terms of who is asking questions, the nature of the questions asked, and the nature of the responses can provide some insight into characteristics of such discourse. Understanding how a student-centered PBL environment unfolds and can be facilitated is the focus this paper.

2. Methods

2.1 Data Sources

The participants in this study were five second-year medical students, who were experienced in PBL, and a master facilitator. The facilitator had extensive experience in facilitating PBL as one of the pioneers in developing this method. Students worked on the problem of a patient who presented with numbness in her feet for five hours over two sessions. The sessions were videotaped and transcribed. In addition, the researcher reviewed the videotapes with the facilitator and interviewed him regarding his goals and strategies for particular discourse moves and his beliefs about learning.

2.2 Coding and Analysis

The entire transcript was coded for the types of questions and statements in the discourse. These were coded using a taxonomy of question types and several additional categories that were developed to capture monitoring, clarification [6], and group dynamics questioning (see Table 1). Three major categories of questions were coded. Short answer questions required simple answers of five types: verification, disjunction, concept completion, feature specification, and quantification. Long answer questions required more elaborated relational responses of nine types: definitions, examples, comparisons, interpretations, causal antecedent, causal consequences, expectational, judgmental, and enablement. The meta category referred to group dynamics, monitoring, self-directed learning, clarification-seeking questions, and requests for action. Any questions that did not fit into these categories were classified as uncodeable.

Statements were coded as to whether they were new ideas, modifications of ideas, agreements, disagreements, or metacognitive statements. Each of these statements was also coded as to its depth. Statements were coded as simple if they were assertions without any justification or elaboration. These corresponded to responses to the short answer questions. These included verifications, concept completions, and quantities. Elaborated statements went beyond simple assertions by including definitions, examples, comparisons, judgments, and predictions. These would be responses to long answer question types 7-10, 14, and 15 in Table 1. Statements were coded as causal if they described the processes that lead to a particular state or resulted from a particular event (i.e., responses to question types 11-13). Statements were also coded as to whether they were read from the case information, repetitions of a previous statement, or uncodeable statements.

To examine how productive the discourse was, all utterances were coded as to their content to describe how the students' traversed the conceptual space. The conceptual space has two parts—the learning space and the problem space. The learning space is a broad set of issues that are considered in the context of developing a causal explanation of the patient's problems. This consists of alternative hypotheses and basic science concepts. Embedded in this is the much more detailed problem space, which includes all the causal mechanisms that account for the patient's signs and symptoms. To examine this, a hierarchical concept map was created that included all 123 nodes in the learning space. This was constructed using standard medical textbooks and was checked by an expert physician. In addition, this was cross-checked against the learning objectives for the problem.

To make the analysis tractable, the 123 nodes that were coded were collapsed into 64 nodes. All nodes of this condensed space were classified as to whether they were in the broader learning space or the deeper problem space. Twenty-five nodes were in the broader learning space. These included items such as general anatomy and physiology of the nervous system and various spinal and neurological disorders. The problem space contained 39 nodes. These were specific to the patient's diagnosis and included items such as Vitamin B-12 deficiency, symptoms related to this disease, and biochemical pathways involving B-12 utilization.

The first 10 min of hours 2-5 was coded by two independent coders. Interrater agreement was 91% for question coding, 88% for explanations, and 90% for the learning space.

3. RESULTS

3.1 Questions and Statements

The distribution of questions over the two sessions is shown in Table 2. A total of 808 questions were asked, 465 by the students and 343 by the facilitator. This far exceeds the number observed in traditional classrooms [6]. The students asked 226 short answer questions, 51 long answer questions, and 188 meta questions.

Of the short answer questions, the modal question type was to elicit the features of the patients' illness from the medical record, for example when Jim asked "Does it say anything about medications?"

The facilitator asked 39 short answer questions, 48 long answer questions and 256 meta questions. Short answer questions were generally used to focus students' attention. Long answer questions often asked the students to define what they had said or interpret information as for example when the facilitator asked a student "But I mean what produces the numbness at the bottom of the feet?" Meta questions were the dominant mode for the facilitator as he asked the students to evaluate one of their hypotheses "Well yeah, multiple sclerosis. How about that? How do you feel about that?…" These statements also included monitoring the group dynamics as he asked, "So Mary, do you know what they are talking about?"

The facilitator asked comparatively few content-focused questions. Both the students and facilitator asked many fewer questions in the second session than in the first. However, the students asked the same number of long answer questions in the second session as in the first. The facilitator continued to use short answer questions to help focus attention—again with the same frequency as in the first session. One reason for the

Table 1. Categories of questions

Question Type	Description	Example
Short answer		
Verification	Yes/no responses to factual questions.	Are headaches associated with high blood pressure?
Disjunctive	Questions that require a simple decision between two alternatives.	Is it all the toes? Or just the great toe?
Concept completion	Filling in the the details of a definition.	What supplies the bottom of the feet?
Feature specification	Determines qualitative attributes of an object or situation.	Could we get a general appearance and vital signs?
Quantification	Determines quantitative attributes.	How many lymphocytes does she have?
Long Answer		
Definition.	Determine meaning of a concept.	What do you guys know about pernicious anemia as a disease?
Example	Asks for instance of a concept or event.	When have we seen this before?
Comparison	Identify similarities and differences between two or more objects.	Are there any more proximal lesions that could cause this? I know it's bilateral.
Interpretation	A description of what can be inferred from a pattern of data.	You guys want to tell me what you saw in the peripheral smear?
Causal antecedent	Asks for an explanation of what state or event causally led to the current state and why.	What do you know about compression leading to numbness and tingling?
Causal consequence	Asks for an explanation of the consequences of an event of state.	What happens when it's, when the, when the neuron's demyelinated?
Enablement	Asks for explanation of object, agent, or processes that allows action to be performed.	How does uhm involvement of veins produce numbness in the foot?
Expectational	Asks about expectations or predictions (including violation of expectations).	How much, how much better is her, are her neural signs expected to get?
Judgmental	Asks about value of idea, advice, or plan.	Should we put her to that trouble, on the basis of what your thinking is?
Task oriented and meta		
Group dynamics	Lead to discussion of consensus or negotiation of how group should proceed	Do you know what they are talking about?
Monitoring	Help check on progress, requests for planning	Um, so what did you want to do next?
Self-directed learning	Relate to defining learning issues, who found what information	So might that be a learning issue we can, we can take a look at?
Need clarification	The speaker does not understand something and needs further explanation	Are you about micro vascular damage which then causes the neuropathy?
Request/ Directive	Request for action related to PBL process	Why don't you give [scribe] a chance to get the board up?

drop in meta questions by both the students and facilitator is that they were no longer planning their self-directed learning in the second session. Aside from a brief discussion of the resources the students used in their independent research, this was no longer a focus of discussion. Instead, on the second day the students focused on refining and elaborating their ideas.

An analysis of the kinds of statements that students made provides a window into students' collaborative knowledge construction. If the discussions were

Table 2. Distribution of question types over two tutorial sessions

		Session 1		Session 2	
□	**Speaker→**	F	S	F	S
Short Answer	Verification	10	31	9	36
	Disjunctive	1	9	2	5
	Concept completion	7	9	5	18
	Feature specification	2	91	2	20
	Quantification	0	0	1	7
	Total Short Answer	20	140	19	86
Long Answer	Definition	14	4	3	4
	Example	0	0	0	0
	Comparison	0	3	0	0
	Interpretation	13	8	3	3
	Antecedent cause	6	6	1	5
	Causal consequence	0	3	1	4
	Expectational	1	1	2	7
	Judgmental	1	0	2	0
	Enablement	1	1	0	2
	Total Long Answer	36	26	12	25
Meta	Group dynamics	29	9	13	4
	Monitoring	67	47	49	27
	SDL	33	12	7	11
	Need Clarification	10	43	5	23
	Request; Directive	30	8	13	4
	Total Meta	169	119	87	69
UC		1	14	3	5
Grand Total	□	225	285	118	180

Note: F is Facilitator, S is Students. UC is uncodeable

student-centered then it is reasonable to expect the students to do most of the talking. Moreover, if knowledge were being collaboratively constructed, the students' statements should be in response to previously introduced ideas. The facilitator should be offering few new ideas making metacognitive statements, monitoring the group's progress in problem-solving and self-directed learning.

This was indeed the case. The facilitator made a total of 243 statements and the students made a total of 3760 statements. The distribution of statement types is shown in Table 3. Clearly, the students are doing most of the talking. The facilitator made few statements, rarely offering new ideas or modifying existing ideas. The facilitator was most likely to offer a comment monitoring the group's progress or encouraging students to consider when a poorly elaborated idea might become a learning issue. Both the metacognitive questioning and statements helped support the students collaborative knowledge construction as they built on the new ideas offered by others, expressing agreement, disagreement, and modifying the ideas being discussed. This was especially important in the second session when the meta statements that he made helped support student elaboration and causal reasoning. In both sessions the majority of statements taken alone were simple statements. In the first session, many new ideas were offered to the group. The students generally worked to maintain consensus and avoid conflicts but they did modify the ideas that were circulating. It is particularly notable that in the second session, there were fewer new ideas and more modification of existing ideas. As the measure of statement complexity shows, the students engaged in more elaboration and causal reasoning in the second session than in the first as they used their new knowledge to flesh out their ideas.

Table 3. Distribution of statement types

□	Session 1		Session 2	
□**Speaker→**	F	S	F	S
New Ideas	1	64	2	36
Modifications	9	563	12	657
Agreements	20	490	13	411
Disagreements	1	51	0	50
Meta	66	383	102	521
Other	11	263	6	271
Total	108	1814	135	1946
Simple	27	911	23	727
Elaborated	3	190	4	283
Causal Elaborated	1	67	0	144
Total	31	1168	27	1154

Collaborative explanations were often composed of collections of simple statements that were elaborated, over several speakers and several conversational turns. For example, during the second session, HB, the facilitator, asked the students how the pernicious anemia hypothesis accounts for their concerns:

HB: MA does that malnutrition vitamin B cover the, the things you were talking about just a minute ago? You were concerned about there's a number of different vitamins that may be involved.

MA: I hmmm.

HB: Can we just leave the, that hypothesis up?

MA: Oh yes. I think that's fine.

DE: Like pernicious anemia is a big one.

MA: Right. That must be the vitamin, the B.

HB: What, what's pernicious anemia?

DE: Uh, it's a deficient, deficiency of cobalamine.

MA: Vitamin B12, cobalamine or..

JM: Or folate.

MA: Or folate.

DE: Yeah, but it's not, that's not pernicious anemia. That's a, also another macrocytic anemia.

MA: Pernicious anemia is specifically.

JM: Oh. You're right. That's right.

DE: And um, you get anemia and you can also get eh, um, peripheral...

MA: Neuropathies.

DE: ... neuropathies.

HB: down there too?

CP: Technically pernicious, pernicious anemia is technically just the loss, the lack of intrinsic factor.

DE: The loss of intrinsic factor. So you don't absorb.

CP: And that's [unintelligible]

DE: You don't absorb.

CP: Right.

MA: Right.That's a good distinction. You see, we...

CP: As opposed to like somebody who had part of their intestine removed and can't absorb.

MA: Right.

CP: But their ileum is gone and they can't absorb the B12. That's different than pernicious anemia, to vit, intrinsic factor.

This is collaborative because students all contributed different parts of the explanation. The facilitator triggered the explanation when he asked MA to evaluate her hypothesis but then, different students offered different pieces of the explanation about pernicious anemia, what some signs might be (neuropathies) and what alternative explanations they can rule out (poor absorption of B12 in the gut). The students were themselves very metacognitive as they monitored their progress and understanding.

3.2 Traversing the Concept Space

The previous analyses examined one aspect of the collaborative discourse, but to make a case for learning, it is important to consider the content of the student talk. The students covered a total of 36 out of the 64 possible nodes in the problem and learning spaces. The nodes they did not discuss were either very general, such as review anatomy and physiology of nerves or related to symptoms that the patient did not exhibit. The material covered by some of the very general nodes was often covered at a greater level of detail and was thus coded at the most specific node possible. The students discussed 25 nodes during session 1 and 28 nodes during session 2. Table 4 shows the number of utterances coded in the learning space and problem space each day.

Table 4. Content Analysis of Tutorial Discourse

□	Day 1		Day 2	
Speaker→	F	S	F	S
Learning space	286	1620	85	907
Problem space	263	2047	226	2359

This analysis demonstrates that the students' talk was productive. They were content focused throughout the duration of the tutorial. They started out broad in the first session discussing both the learning space and problem space at length and they engaged deeply into the problem space content in the second session. As Table 4 indicates, most of the content talk was by the students. The facilitator used his questioning strategies to focus the students into the problem space in the second session but did not ignore the learning space.

3.3 Goals and Strategies

To complement the fine-grained analysis, I conducted a qualitative analysis to zoom out on the goals and strategies of the facilitator. The facilitator was interviewed on his goals and strategies while viewing the videotape. In addition, an interaction analysis session was conducted with a cognitive scientist to further elucidate the data interpretation.

The facilitator's overall goal emphasized that students needed to construct a causal explanation of how a disease leads to a pattern of signs and symptoms. He believed that students learned best through guided exploration of complex, ill-structured problem spaces. He focused on helping students become good reasoners as they looked for consistent mappings between different levels of explanations. Another important goal was helping the students become critical, self-directed learners who are cognizant of the limitations of their knowledge. His overall strategy was to use open-ended questioning and take advantage of the PBL routine. He adapted his questioning and other strategies based on where the students were in their learning and in the PBL process.

One specific strategy that the facilitator often used was to ask students for an explanation as he did when MA offered suggested that multiple sclerosis was the cause of the patient's problem:

MA: Um, just given the idea that numbness in your feet, I had multiple sclerosis as a possibility. She is an older woman and multiple sclerosis, I believe, usually presents in the younger generation 30's and 40's, but it, it definitely can happen in an older person. So…

HB: And tell us what multiple sclerosis is.

MA: Um, Multiple sclerosis is um, a progressive, it's a progressive and chronic debilitating disease um, where you get various points of sclerosis within the brain itself and it can affect different areas of um, of um, people's motor function. And it's called multiple sclerosis because there are multiple areas of these sclerotic plaques that occur in the brain.

HB: What causes those plaques?

This served the goal of placing the students' knowledge in public view and helping the students see the limitations of their understanding. Another strategy observed is that of revoicing in which the facilitator restates what a students has said [16].

MA: And another important um, hypothesis that's come is a vitamin B12 deficiency, which we've crossed out. Hah, because we didn't think she had any malnutrition. However, we found out that um, in the elderly there is a much, much higher prevalence of Vitamin B12 deficiency…

DE: And also I was just, happen to glance at it last night and um, 'cause I was just talking with my husband and, about the um, neurosyphilis and, and uh, the olivopontocerebellar atrophy being pretty serious and progressive and, and I was thinking that vitamin B12 wasn't so much if you treated it. But it, I was reading that it's in a lot of the neur, uh, neural deficits are irreversible.

MA: Uh hmm.

DE: So it is, you know. It does put in my mind it's a more of a serious.

Facilitator: Now you people are saying B12 all the time and yet when you say we eliminated it, you're talking about pernicious anemia, right?

The facilitator has accomplished three goals here. First, he has taken the idea put forth by the students and clarified it for the group as he restated it. Second, he has legitimated Denise's idea. She is a quiet but extremely thoughtful student and is recognized by this move. Third, he made sure this very important idea did not get lost. Pernicious anemia is the cause of the patients' problem and was in danger of being lost from the discussion. Table 5 provides examples of additional strategies that the facilitator used.

Table 5. A sampler of additional strategies

Strategy	Goals
Summarizing	Ensure joint representation of problem
	Establish common ground
	Help students synthesize data
	Move group along in process
Map between symptoms and hypothesis	Elaborate causal mechanism
Generate/ evaluate hypotheses	Help students focus their inquiry
	Examine fit between hypotheses and accumulating evidence
Check that students agree that whiteboard reflects their discussion	Make sure all ideas get recorded and important ideas are not lost
Cleaning up the board	Evaluate idea
	Maintain focus
	Keep process moving
Creating learning issues	Knowledge gaps as opportunities to learn
Encourage construction of visual representation	Construct integrated knowledge that ties mechanisms to effects

4. Implications for Computer-Supported Collaborative Learning

This study demonstrates that, in PBL, the students do a substantial amount of question-asking and explanation construction as students move through a complex conceptual space, indicating that the tutorials are clearly student-centered. Moreover, the teacher's role is that of metacognitive guidance and scaffolding the collaboration. Specific types of questions are strategically used in the service of learning goals. These questions serve as scaffolds that are faded as students internalize the questions [17]. These results suggest that through this apprenticeship in thinking, students see the big picture and integrate large bodies of learning through their learning discourse.

The analysis of an expert facilitator has important implications for providing tools to facilitate online collaboration. These results suggest conversational moves that facilitators might make at different stages of learning and representations that could embody the learning goals and strategies of an expert facilitator.

The role of the facilitator in a face-to-face discussion has several aspects. First, facilitators need to help maintain the agenda and manage time. Second, they needs to ensure that ideas are addressed at a deep, conceptual level. Third, they need to keep the group moving and ensure that everyone participates. These roles are also critical in an asynchronous facilitation but enacting them will have some qualitative differences. In face-to-face tutorials, it is critical to get to the learning issues before a session ends. Session boundaries are not clear in online PBL. Online systems need to consider timeframes and how embedded activity structures can create these boundaries. It is more difficult to keep an online group moving without visual cues available in face-to-face interaction. Finally, it is likely that the facilitator has an additional role in asynchronous PBL –helping the group to converge rather than continuing to diverge. Understanding how to address these differences is critical in developing systems to support both students and tutors in asynchronous discussion.

Typically in PBL, students are working at the same time and place for most of the learning process. Strong group cohesion develops as students work together. Online, it is difficult to obtain the same sense of being immersed in the learning situation [18]. This provides additional challenges for maintaining the online group dynamic given the lack of social context cues [19].

PBL provides a well-described approach to constructivist learning. However it is labor intensive and requires one trained facilitator for each group of students, which is not always practical. Often novices are asked to facilitate with very limited training. Research by Derry, and colleagues suggests that facilitation is quite difficult for novices [20]. Novice tutors do not always know how and when to intervene appropriately. In the novice tutors' struggle to facilitate, they may have difficulty dealing with the group dynamics. The questions that the expert asks can be incorporated as procedural facilitations for the novice tutor by suggesting different questions that might be useful to serve different goals during different stages of learning. The analysis of the questions has been incorporated into a set of procedural facilitations for student tutors in an Educational Psychology class for preservice teachers. Figure 1 shows an example of one of the four prompt cards that a novice facilitator might use during hypothesis generation. These types of hints could be incorporated into an online tutor tool kit. As well, annotated examples of discourse could be provided to model how and when expert facilitators intervene and when they stand back and allow the group to work issues out among themselves. Although this includes very basic information about PBL, it provides concrete examples of questions that the facilitator could ask. Prompts such as these might be incorporated into a set of facilitation tools to support novices in online facilitation. Trained facilitators are a limited resource, so a distributed PBL system might offer an alternative way to deal with this limitation [21]. As noted in the previous section, the analysis of expert facilitation can be used to provide tools to support novice facilitators.

Asynchronous collaboration might offer opportunities for students to be more reflective than they might be in a face-to-face conversation, enabling deeper learning conversations. However, the slower pace of asynchronous PBL might make some of the expert strategies difficult to implement. The slower pace gives the facilitator more time to respond to issues going on in the group but there is a real danger that the flow of the dialogue might be lost. In the face-to-face tutorial, the students made 3760 statements and asked 465 questions. Online, students take many fewer turns and there are significant time lags in students' responses.

This suggests that there needs to be some adaptation to accomplish PBL asynchronously. A pilot study was conducted in Spring 2001 with 2 groups experienced in face-to-face PBL using the STEP PBL system (www.estepweb.org) [22]. This system is an innovative web site designed to support facilitated problem-based discussions of video-cases [23]. The site has a student module which helps structure the students collaborative PBL, a tutor toolkit to provide resources for facilitation, an asynchronous environment for online collaboration, video case materials, and hypermedia information resources that cover learning sciences content. The student module included a whiteboard, as in traditional PBL and the asynchronous environment was a threaded discussion. For the pilot study, an experienced tutor facilitated the groups. Students would log on at different times and at irregular intervals. This posed a major challenge when the facilitator would ask a student to explain what they meant and the student might not log on for several days by which time the conversation was on another topic. The students did not often respond to the facilitator or each other. Rather, there seemed to be parallel ideas that did not converge to a final product. The facilitator needed to use email as a back channel to keep the students on schedule. Both the system and the task structure have since been revised to address some of the problems identified in the pilot study [21].

As in other CSCL systems, the responses to students' posts and whiteboard entries need to be flagged so students can respond. One possible solution to this problem would be to have the system email the participants (including the facilitator) when there is a new post to remind them to log in. Because of the nature of threaded discussions, there need to be mechanisms that make the flow of the discussion

2) GENERATING MULTIPLE HYPOTHESES

Students should brainstorm their first instincts about:

IDEAS: how to solve the problem

FACTS: information we know about the problem

LEARNING ISSUES: information we need to know

ACTIONS: what we can do to start solving the problem

The scribe will begin to write down what the group says on the white board/ big paper.

Ask for clarification of terms written down in the FACTS and IDEAS columns.

EXAMPLES:

- What does that term mean?
- What does "expert" mean in this case?

If students can't clarify or define their ideas, these become LEARNING ISSUES

Goal: To help students understand what they don't know.

Figure 1. Example prompt card for facilitators

more transparent to the participants

A CSCL system adapted for online PBL needs to have representations that support problem-based discourse. One way to accomplish this might be through anchored collaboration in which the whiteboard serves as an anchor for conversations [24]. There needs to be a mechanism for the facilitator and other students to negotiate and discuss the contents of the whiteboards in an integrated fashion. Pilot work with the STEP system suggests that integration of disparate workspaces is critical in distributing some facilitation onto the system and maintaining the flow of PBL activities. A more integrated system might contain links and annotations that connect the discussion and whiteboard.

Representations can also embody the goals of PBL. Consider the general goal of the facilitator to help students construct causal explanations that connect theories, data, and proposed solutions. Representational tools constrain student discourse to if they can support these goals—for example, a concept-mapping tool could support the construction of causal explanations to the extent that it is salient that students need to tie problems to solutions [25]. The representation might emphasize what students need to observe in the problem (e.g., teacher's goals, activity structures, assessments). It is critical that the various workspaces be integrated such that students map among the spaces, i.e., the whiteboard, asynchronous discussion, and other visual representations. In addition, features that support social presence such as pictures and threads for limited social discourse might be useful to help create group cohesion.

Sequencing of activities and task structures are other ways to offload some facilitation tasks onto a system. Students might be asked to generate summaries after some period of time or to negotiate a joint summary of their problem representation and solution to date. The system might ask students to update their hypothesis list whenever they log onto the system and ask them to explain why they are modifying their ideas as the expert facilitator does at regular intervals. As they are getting ready to log off, the system could have students compile a list of the learning issues they plan to research before the next time they log in. They might also identify resources that they used. This information could then be passed onto the facilitator and be posted to the group whiteboard.

5. Conclusions

The analysis of expert facilitation provides four major lessons about constructivist teaching. The first set of issues relate to how facilitators with varying levels of expertise can be trained and supported to be more like experts as they gently guide learners through complex conceptual spaces. The second is to provide guidance to offload facilitation functions onto an asynchronous PBL system. The third issue relates to embodying the goals and strategies of the expert facilitator into the visual representations that are available in the system. The fourth issue addresses how facilitating asynchronous and face-to-face discussions differ. These ideas for system design are hypotheses that need to be tested to understand how PBL and other constructivist instructional models can be implemented to support productive discourse. Similar analyses need to be conducted of online facilitation to better understand how what is means to be an expert facilitator in an asynchronous environment.

6. Acknowledgments

This research was funded by a National Academy of Education Postdoctoral Fellowship and an NSF ROLE grant. I thank Howard Barrows for being the subject of this study and Allan Collins for advice on data analysis

7. References

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