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Authority and convergence in collaborative learning

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Abstract

Teachers and students have established social roles, norms and conventions when they encounter Computer-Supported Collaborative Learning (CSCL) systems in the classroom. Authority, a major force in the classroom, gives certain people, objects, representations or ideas the power to affect thought and behavior and influences communication and interaction. Effective computer-supported collaborative learning requires students and teachers to change how they understand and assign authority. This paper describes two studies in which students' ideas about authority led them to converge on what they viewed as authoritative representations and styles of representation too early, and the early convergence then hindered their learning. It also describes a third study that illustrates how changes to the CSCL system CAROUSEL (Collaborative Algorithm Representations Of Undergraduates for Self-Enhanced Learning) improved this situation, encouraging students to create representations that were unique, had different styles and emphasized different aspects of algorithms. Based on this research, methods to help students avoid premature convergence during collaborative learning are suggested.

Keywords: Computer-mediated communication; Cooperative/collaborative learning; Evaluation methodologies; Learning communities; Teaching/learning strategies

1. Introduction

Determining the nature of successful collaboration and being able to measure and document it when it occurs are critical to evaluating the impact computer-supported collaborative learning activities have on learning. In the past, measures such as the amount of use of a computer-

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supported collaborative learning system, the extent of students' convergence on a similar understanding of a problem or solution, and the development of a community of learners have been used.

All of these measures have limitations. Perhaps the students enjoy using the system and use it frequently, but learn little. Students, similarly, can converge on an incorrect understanding of a problem and solution. A community of learners can be built, but the community could focus on issues peripheral to what the learning activity was designed to teach.

In fact, typical classrooms are already communities of practice and learning. Teachers and students, by the time they encounter CSCL systems, have considerable experience in teaching and learning. College students, the students we have been studying, are not novices at assuming the role of student; they are skilled students experienced in social roles, norms and conventions that effect social interaction and communication. They already work together to find, produce and manage shared knowledge in their classes.

This paper describes situations where we observed system use, knowledge convergence and community building, and concluded that these were not necessarily good indicators of success. This is because the authority structure that exists in communities of students and teachers prior to entering into the collaborative learning activity had a large impact on subsequent learning and collaborative learning activities.

Authority is a major force affecting classroom communication and social interaction, which gives certain people, objects, representations or ideas the power to affect thought, opinion and behavior. We found that the authority students give certain representations and representational conventions can have a negative effect on collaborative learning. For undergraduate students, whether or not a certain type of representation is used to build understanding has more to do with the authority of the representation than its explanatory power. We found that when students focused on representations with high authority and low explanatory power, their learning was impeded.

To demonstrate this problem and illustrate how to counter it, we describe three studies. In the first study, we observed computer-science students learning algorithms collaboratively in small groups. Subsequently, we created CAROUSEL, a CSCL system supporting these students in algorithm learning through creating, sharing and evaluating explanatory representations of algorithms. In the second study, we observed students using the system. In analyzing the data from the first two studies, we discovered the impact authority and authoritative styles and representations have on how students interact and learn in collaborative situations. Consequently, we revised CAROUSEL and studied its use by students learning more algorithms.

In the first observational study, the students' perception of authoritative knowledge led them to difficulties when they engaged in collaborative learning. They used one representation presented by their instructor to answer all questions posed to them, regardless of whether or not it was appropriate to use. They converged on a shared but incomplete understanding based on this one representation, indicating that convergence on a shared understanding early in the learning process can be a hazard.

In the two subsequent studies involving CAROUSEL, students created, shared and evaluated their own representations of algorithms. In the first study we found that the type and style of the representations converged over the course of five weeks. At the beginning of the study, many different types of representations were created, including ones with 3-D animation, sound and text stories, some using sophisticated metaphors. By the end of the study, though, most of the representations were explanatory graphics and text representations. These were similar to representations one would find in the lectures students attended and in their textbook, a type of representation that most students would consider authoritative.

Multiple representations would seem to help students learn difficult concepts by making them view the concepts from different perspectives (Feltovich, Spiro, Coulson, & Feltovich, 1996). Feltovich and colleagues argue that working in groups will necessarily bring multiple perspectives. However, we found that convergence is also a likely occurrence, even when teachers or classroom conventions are not exerting authority during a learning activity. Students judged representations often on their ability to fit with cultural and classroom norms, rather than their ability to explain, communicate or enlighten.

Based on these results, we revised CAROUSEL. We then used it in a larger scale study and found that simple changes in how we preserved the students' anonymity, the type of feedback they could receive from peers and encouraging divergence led students to not converge on an authoritative classroom style. We also found that students were representing different aspects of algorithms that had not been represented at all in the first study.

Based on this research, we suggest methods to avoid premature convergence with CSCL systems. We encourage CSCL system developers to acknowledge authority issues and find productive ways to grant authority to students in learning contexts. Also, it is important to either adapt the system to the current social activities and arrangements in the classroom or to make it explicit how the social arrangement will change and have participants accept and take ownership of that change. The authority of the people and the representations used in the classroom needs to be considered when designing and conducting collaborative learning activities.

2. The role of authority and convergence

A major force affecting classroom communication and social interaction is authority. Authority is the power given to certain people, objects, representations or ideas to affect thought, opinions and behavior. In the typical classroom, the teacher is an authoritative figure. Examples and other kinds of expository representations the teacher provides and the styles and conventions he employs acquire importance and assume authority in the eyes of the students. This often leads to an implicit belief by the students that everything they are expected to know will either be explicitly provided by the teacher, or can be derived from his explanations and examples. This can lead to a stultifying classroom, where students see themselves as passive absorbers of knowledge, rather than as constructive knowledge builders.

Collaborative learning practices are often a liberating and democratic influence, creating new freedom in the classroom. These can be used to take a classroom out of the normal "one authority/many listeners" mode of learning to a "one facilitator/many active participants" mode of learning. CSCL research often assumes students' ideas, understanding and communication styles are diverse, and that collaborative learning succeeds when the group converges on a common understanding of the concept to be learned. This research also often assumes that normal classroom practices are based on an information transmission model, where teachers present information to passive students. However, these two assumptions are inconsistent. If students obtain information primarily by absorbing it from one source, the teacher, prior to engaging in collaborative learning activities, it is unlikely that the students will produce different knowledge and ideas, while subsequently collaborating.

Somewhere between these two assumptions lies the truth. Students do differ and do not absorb information in the same way. However, they are often working with a similar set of assumptions, acquired from similar sources. Students and teachers operate within a social system with methods for assigning, recognizing and understanding authority that makes it difficult for diversity to be recognized, acknowledged and effectively used by students. This also means that students may converge on an understanding that is recognizable as authoritative, rather than an optimal understanding.

CSCL systems, to be successful, require students and teachers to change how they understand and assign authority. Students need to assume more authority, assign authority to their peers, and to value their own thoughts and ideas. However, this is not an easy transition to make.

Strangely, the discourse of learning often avoids the topic. Simon (1980) argues that authority has such a bad reputation that people avoid examining it. Authority, he argues, is seen as unjust, unnatural and anti-democratic, but also is always present in social interactions. However, for a community to have common goals, communication and shared knowledge, authority is essential: A community needs “authority to unify its actions” (p. 50).

2.1. Convergence

Convergence is the collective arrival at a shared meaning during collaborative learning. In this paper we use the term to also mean the collective acceptance of a representation or explanation as reflecting the correct meaning of a concept. Convergence is seen as a positive phenomenon and proof that learning has occurred in collaborative learning research. For example, Roschelle presents a case study of convergent conceptual change, and argues that the crux of learning by collaboration is convergence. “Few theories account for the achievement of convergence in the face of tendencies for meanings to diverge. This potential for divergence is particularly acute in science education. . .A serious account of science learning must provide an analysis of how convergence is achieved despite these tendencies” (Roschelle, 1992). In the case study he details, two students arrived at a shared understanding of the notion of acceleration while collaboratively working with a microworld simulation on a computer.

We take the position that while convergence on correct interpretations is indeed a goal of collaborative learning, it must come as a consequence of considering and critiquing divergent, alternative meanings first. Premature convergence on a particular meaning or representation, especially when solely based on its perceived authority or when the shared understanding is incomplete or incorrect, is not a desirable outcome of collaborative learning. In other words, divergence must precede convergence, and the process of convergence must involve the pruning away of misconceptions and the selection or construction of explanations that accurately and fully reflect the concept being learned. It is only under these circumstances can convergence be taken as proof of learning. Our investigations reveal that students exhibit a tendency to prematurely converge on representations based on their perceived authority, rather than on their usefulness for problem solving or even in expressing the concept.

2.2. Classroom authority

CSCL researchers assign more authority to students with their systems than is normally assigned under traditional instruction in the classroom. With these systems, the instructor acts more as a facilitator than an authority figure, and the students have more authority and learning responsibility (Koschmann, 1996). However, one of the important roles of an instructor is to exert and control authority (McCroskey & Richmond, 1983). Instructors, though, usually do not acquire authority for its own sake, but instead gain authority to influence student learning practices. Classroom management practices, such as giving assignments, motivating students to participate in learning activities, and helping students become better members of the class, rely on the teacher having authority (Richmond & Roach, 1992).

Power and authority, however, have to be granted, and in the classroom the students hold the ability to grant authority. Although the institutional status of an instructor gives some initial authority, students must consent and comply with the teacher's plans for her to have authority. To say, as Jackson does (1976), that students have no agency or power in the classroom just because the students have to be there, ignores students' ability to resist. Richmond and Roach give the example of substitute teachers who are unable to gain authority and in extreme cases are driven crying from classrooms, to show how students can resist granting authority (1992).

College students' resistance to authority tends to be passive and partial, such as complying reluctantly, i.e. doing the minimum needed to pass the class, deceiving the instructor, collaborating with others on individual assignments and cheating. Student resistance can also be constructive, such as asking clarifying questions during class, assisting other students in learning the material, studying together, and providing constructive feedback. Constructive resistance to authority can help students become more active learners (Burroughs, Kearney, & Plax, 1989).

2.3. Missing contract/missing authority

Students find it difficult to communicate with each other when the authority of an instructor is missing. Stubbs (1983) studied how teachers control communication in the classroom. Teachers often control what is discussed and how it is discussed. Also, for a student's solution to be considered correct, the student has to recognize an instructor's authority and has to adopt his methods of communication about the topic.

Even in classrooms where more progressive teaching methodologies are practised, teachers often still maintain considerable control over what the students are doing. Edwards and Mercer (1992) studied classrooms where small-group learning was being used and found that although the students appeared to be working independently, the teacher was really controlling the discussion and actions of the group.

Similarly, Guzdial's CoWeb, a CSCL system that has college students build knowledge collaboratively on the Web, relies on the instructor's involvement and monitoring of student activity. "The teacher's attitude and involvement is critical—since so many students were in the CoWeb mostly to hear from the teacher, a missing teacher might lead to less student involvement" (Guzdial et al., 1999). Even though the college students using CoWebs in the classroom may no longer see the teacher as the main source of information, they still place authority with the teacher through valuing the teacher's opinions and approval.

Studies of how undergraduate students engage in collaboration as part of their classroom activities suggest that the students dislike and resist efforts to make them engage in collaborative learning (Hmelo, Guzdial, & Turns, 1998; Newstetter & Hmelo, 1996). Perhaps these students were resisting the teacher's authority, or perhaps they were resisting how the teacher was not adhering to their classroom contract. Jones' study of two New Zealand classrooms documented how students exerted control over the teacher's curriculum and methods. The students resisted when the teacher tried to have them learn something other than facts, and when the teacher did something other than lecture and testing on notes (Jones, 1989).

3. Observing students learning algorithms

However, we found in a study reported here that students do not always resist collaboration and often initiate and engage in collaborative learning as part of their normal learning practices. We found this in a qualitative study to discover the methods, resources and strategies computer-science students in an introductory algorithm analysis class use to learn algorithms.

3.1. Method

Sixteen students from an algorithm analysis course volunteered. Students were given extra credit in their course for participating. They were told their performance in the study and in answering the questions posed to them would not affect the extra credit they received for participating or their course grade in any way, and the instructor of the course would not know about their performance in the study.

We observed and videotaped 16 students in six groups of two to three students learning the Quick Sort algorithm, a sophisticated sorting algorithm, and then answering a set of problem-solving questions. Subsequently, they were interviewed, either in groups or individually, to learn about how they normally study algorithms. The students were told to bring their textbook and any other resources they normally use for leaning algorithms. Once they arrived, they were told the purpose of the study, to learn more about what methods, resources and strategies they use in learning algorithms. The students were shown a videotaped lecture on the topic of the Quick Sort algorithm. This lecture resembled the lectures they normally attended, i.e. it was presented by their instructor, who used a white board and markers, his usual method of presenting the material. The students were given lecture notes, something that is normally given during their class, which summarized the material and presented the pseudocode (i.e. a programming language-independent description) of Quick Sort. After viewing the videotape, the students discussed the lecture and worked together to answer questions given to them by the experimenter about the algorithm.

3.2. Results and discussion

Because the students reported in the interviews that their most common method for studying was to study and work on problems in groups, this research had some ecological validity. The students said they regularly gathered together to study, complete homework problems and even program together. Constructive and collaborative learning was already a natural, normal learning process for the students. They reported that the way that they studied in groups for this research was similar to their normal practices, except in this case they were not familiar with all the members of their group. Students were grouped together randomly, and the students were quite different from each other. The students' sex, race, work experience, previous schooling, nationality and age varied considerably. Often, students who had never met were grouped together. Despite this, and despite the fact that the students were not explicitly asked to collaborate with other members of their group, all students chose to work together and learn from each other, and all but one of the students reported enjoying working as a group.

Our overall conclusion was that the students' perception of classroom authority and authoritative knowledge negatively affected their learning. That learning was incomplete was clear from the fact that when the students tried to answer questions that required using some source other than the lecture, they failed to answer these correctly.

We observed the process of how they produced answers to these questions. They usually constructed an explanation based on their understanding of the lecture, rather than investigate a question using the textbook they had brought with them. One representation in particular, shown by the instructor, was considered to be the most authoritative of all. This graphical representation was central to all of the students' understanding of the algorithm, and the students tried to answer *all* questions about the algorithm by referring to this one representation. The representation had acquired the authority of its presenter, their instructor, and the students believed by working out other examples using this single representation, they would be able to learn all they would need to know about this algorithm.

The few students who did look at the textbook to answer these questions were not able to convince their peers to do the same or to consider their answers, even when their understanding was correct. Most students in the groups did not consider these other resources and the answers or understanding derived from them authoritative. These observations led us to the conclusion that the students' perception of classroom authority and authoritative knowledge negatively affected their learning.

3.3. Classroom contract

The students appeared to believe in an implicit contract between the teacher and the class. This contract had been violated when in our study they were asked questions that required them to do their own investigating rather than relying on the instructor's lecture. The students reported believing that what should and does happen in the classroom is that the teacher will tell them what to learn and how to learn it. They believed that if they were expected to know anything not explicitly said by the instructor, they should be able to be derive that knowledge by working out example problems given in class. If they fail to learn something the teacher expects them to know, it is not that the teacher did not address the topic in class, only that they were not attentive enough to the details of what was said and what could be derived from what was given. Everything that needed to be learned should be in the lectures.

This contract is similar to the one Sizer discovered in high schools (1984). He describes students and teachers making a contract to reduce discomfort. The students are seen as trying to reduce stress and work, and teachers are seen as wanting to keep up an appearance of control. To come to an agreement, teachers don't demand much work and students behave.

Our study participants seemed to believe the teacher was trying to reduce their work and stress. They reported that they found the lecture notes provided by the teacher easier to understand and use than their textbooks. The lecture notes handed out by the instructor of this algorithms course gave more of an overview of the concepts covered in each lecture, provided less of the reasoning behind using a particular algorithm to solve a problem, used fewer mathematical symbols than the textbook, and gave less background information and comparisons with other algorithms. The lecture notes summarized the main concepts in the textbook, highlighting the key points from the lecture that the instructor expected the students to know. Most students said they did not use the textbook until the night before an exam to reinforce the material in their notes. The lecture notes were considered their most important learning resource, since the notes reflected the intentions of the instructor. The implicit contract the students believed they had with the teacher involved the teacher making it easier for them to learn the expected material.

For similar reasons, the students relied on one graphical representation presented by the instructor in the videotaped lecture to answer all the questions about the algorithm. The students seemed to believe the contract would not be violated and that the representation could be used to answer all the questions posed to them. However, the questions posed to them could be correctly answered only by applying other representations and concepts.

3.4. Learning problems arising from adherence to the classroom contract

Problems that the students had in learning the Quick Sort algorithm primarily had to do with their reliance on an authoritative representation. They almost exclusively used a single representation of the algorithm presented in the video (a recursion tree diagram, a type of diagram commonly used by experts to explain recursive algorithms). Groupthink (Janis, 1967) was a problem for all of the groups. Often the students would convince each other that explanations based on a faulty understanding of the algorithm were correct. They convinced each other that they did not need to use the textbook to answer the questions, and even decided not to accept correct answers.

Imitating and examining an example presented in the videotaped lecture was the students' main learning strategy. The students seemed to believe that if they attacked problems in a manner similar to one of the instructor's examples, they would be able to correctly answer all of the questions, even though not all the information they needed to answer the questions was in that representation of the algorithm and even when they could not make any connection between the question asked and the example.

All the students originally believed that if they worked out enough examples, drawing diagrams similar to the one created by the instructor during the lecture, and thought hard about the diagrams, they would be able to answer all of the questions. However, the students realized their understanding of the algorithm was incomplete, when they encountered questions about steps not explicit in the recursion tree diagram and had difficulty answering them. This was a clear clue to the low explanatory power of the recursion tree diagram. However, instead of considering other representations and explanations available to them, they struggled to *derive plausible explanations* from this one representation that did not contain any information that would be helpful with those questions. The information to answer these questions was available to them in their textbook. But even when students were observed using the textbook, it was clear they were frustrated and found it difficult to integrate their understanding of the algorithm and their notes with the descriptive material in the textbook.

Students prematurely converged on one representation and understanding of the algorithm. The instructor did use another representation during the lecture, the pseudocode. However, he spent more time explaining the algorithm using a recursion tree diagram, and thus, lent the graphic representation more authority. The selection of a representation to use to understand the algorithm had to do with the authority assigned to it, rather than its explanatory power. The learning problems found by this study are consistent with Milgram's studies on student obedience to authority (Milgram, 1963, 1965). Too much conformity can lead to Groupthink, during which a group converges on a poor decision or solution.

When Gifford and Enyedy studied how students used the Probability Inquiry Environment (PIE), they found another example of premature convergence. When students tried to reach a consensus on probability questions, they chose similar poor solutions (1999). The students, they say, often chose the first solution that they could agree on, rather than continue to consider and explore alternatives.

Students seem to want to simplify complicated things. They have a reductive bias, in which "only one of, or a small number of, the legitimate and useful ways a topic or phenomenon could be construed are recognized or considered, thus limiting understanding" (Feltovich et al., 1996). This happened in this study as well. The students adopted a single representation and understanding and applied that representation, even when it was not appropriate to do so. "Students seem to prefer single models in learning and understanding. These restricted perspectives are then overextended in ways our research has shown to be detrimental to learning" (Feltovich et al., 1996).

One might argue that the problem that the students faced had to do with their lack of knowledge about the material and the merits of different types of representations. However, in this case, the students were aware that the representations they used did not answer the question posed, and yet most students decided to use that representation to invent an answer anyway, rather than even consider different types of representations that either were presented in the lecture or were present in materials they had brought with them to the study. The groups silenced students who considered more than one representation for solving the problem, even though these students often had the correct solution. Students can not learn to differentiate the merits of different types of representation, if they are only willing to consider one.

4. Creating, sharing and evaluating multiple representations

To combat premature convergence and the reductive bias, we propose that students should engage in an active process of representation *creation, sharing* and *collective evaluation*. This process should help combat this tendency of overextending authoritative representations. Students are more likely to accept representations as being incomplete and partial when created by their peers, rather than by an authority figure. Thus, they may be better able to understand that different aspects of the algorithm need to be understood, and that different representations de-emphasize, as well as highlight, different aspects. By sharing their representations, they will be better able to compare their understanding with others.

CAROUSEL was built to help students create, share and evaluate their representations of algorithms. It was used in two studies: a pilot study with 12 students in a beginning data structures course and a larger study with 60 students in an algorithm analysis course. The system collected and displayed student-created representations and collected the ratings students gave to the other students' representations for six characteristics of these representations: usefulness, understandability, familiarity, salience, contiguity, and pleasure.

4.1. Pilot study

4.1.1. Method

Twelve students in a beginning data structures course volunteered to participate. Students were given extra credit in their course for participating. The students were given extra credit based on how much they participated (i.e. whether they just took the posttest, whether they created a representation, and/or whether they evaluated representations). They were told their performance in the study, the quality of the representations they created and their performance on the posttest would not affect the extra credit they received for participation or their course grade in any way, and the instructor of the course would not know about their performance in the study.

CAROUSEL was used to capture, store and display student representations of algorithms, and to capture, store and display student evaluations of these representations. Students could add to a Web site their representations, in the form of text, image or audio/visual files. Students in this study chose to work with a wide variety of media, including text, graphics, sound and animation, based on their personal preferences.

To evaluate the representations, students used a form asking them to rate characteristics of the representation using a Likert scale of 1–5. For the rating, 1 represented the lowest value and 5 the highest for all dimensions. These characteristics were:

- Usefulness (How central was this representation to your understanding of the algorithm?)
- Understandability (How easy was this representation to understand?)
- Salience (How well did this representation point out the important features of the algorithm?)
- Familiarity (How familiar were you with the content of the representation?)
- Pleasure (How much did you enjoy the way this representation communicated the algorithm?)
- Contiguity (How well did this representation connect with the other representations for this algorithm?)

The experiment occurred over four weeks with three identical phases for three different algorithms. The students were given a printed description of an algorithm, using pseudocode, and asked to study and understand it themselves. Following this, each volunteer was asked to create a representation to explain the algorithm. They then used CAROUSEL to store their representations and to exhibit the representations to other students in the volunteer group. This activity took place over a 1-week period.

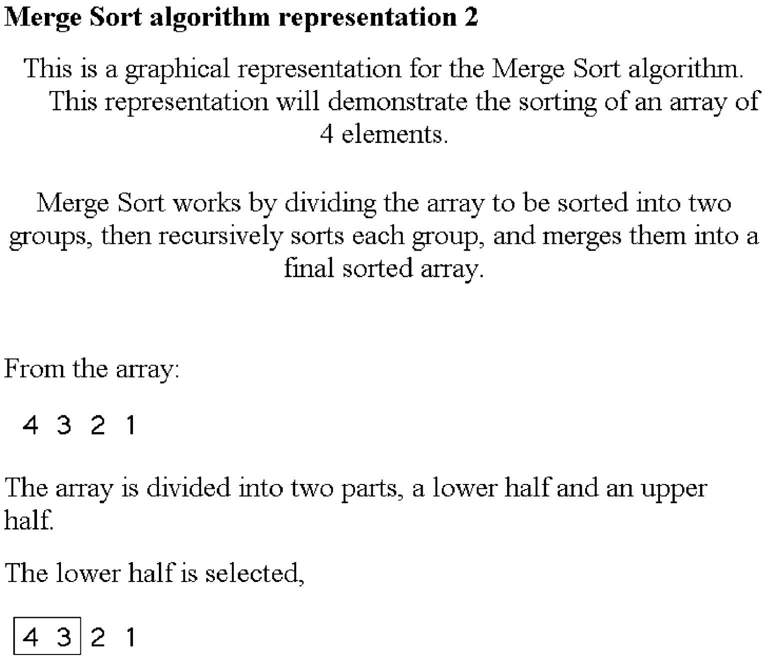
Once representations were visible to the group, the students reviewed and evaluated the representations using CAROUSEL. This activity took place over a 1-week period. After the week for the evaluating task was over, the students took a posttest to measure their understanding of the algorithm. The posttest scores were not revealed to the students. The activities for the three algorithms overlapped, so that most weeks they were creating a new representation and reviewing representations from the last assignment in the same week.

The algorithms covered over the three weeks in order were: the algorithm for the Fibonacci number series, the Selection Sort algorithm and the Merge Sort algorithm. The algorithms were covered in this order, because it reflects the order that these algorithms are covered in the introductory algorithm course at Auburn University.

4.1.2. Results

At the beginning of the study, students chose to work with a wide variety of media, including text, graphics, sound and animation, based on their personal preferences. However, over the course of the study (5 weeks), the students converged on a simple style, one incorporating primarily simple graphics and text. For the first algorithm approximately 64% of the representations were text only, 9% were text and graphics, 9% included animation and sound, and 18% employed more complex media. For the second algorithm, the number of text-only representations decreased (37%), those with graphics increased (50%), and the use of animation and complex media decreased (18%). By the last algorithm, only text representations (57%) and representations with graphics (43%) were used. The most common style used was a "walk-through" style, where they walked through the operations of an algorithm on a small data set, involving simple graphics and text (Fig. 1).

Students were tested after they created representations to measure their knowledge of the algorithm. Test scores suggest that the constructive activities do help learning. For two of the three algorithms that were used in the pilot study, there was a significant positive correlation



Merge Sort algorithm representation 2

This is a graphical representation for the Merge Sort algorithm.
This representation will demonstrate the sorting of an array of
4 elements.

Merge Sort works by dividing the array to be sorted into two
groups, then recursively sorts each group, and merges them into a
final sorted array.

From the array:

4 3 2 1

The array is divided into two parts, a lower half and an upper half.

The lower half is selected,

4 3 | 2 1

Fig. 1. This part of a representation for the third algorithm, Merge Sort, uses text and graphics that walk a student through an example.

between creating and sharing a representation and posttest scores ($r = 0.635$, $P = 0.07$; $r = 0.663$, $P = 0.05$), compared to students who only evaluated others' representations. There was no control group in this study, but students could choose whether to just evaluate the representations or to create and evaluate representations, making the above comparison possible.

4.1.3. Discussion: students building authority based on convention

When an instructor asserts no authority in a CSCL activity, students build authority using other means. In the case of our pilot study with CAROUSEL, the students found authority in the representational styles used in the textbook and lectures. Over the course of the study, students moved from individualistic, metaphor and media-rich representations at the beginning of the study to an explanatory, example-based style with graphics and text. They converged on a style that mimicked what they saw in the textbook and lectures.

All the representations in the study were rated by one of the researchers on a scale of 1–5 with 1 being a rating for representations that are least like a textbook or classroom explanation and 5 being a rating for representations that are most like a textbook or classroom explanation. These ratings increased over time with each new algorithm: the first algorithm had an average rating of 3.4; the second had 3.9; and the third had 4.7.

The average of all the ratings the students gave each representation is significantly positively related to the rating of how similar that representation is to a textbook or classroom explanation ($F\,(1, 24) = 3.9$, $P = 0.06$). Multiple linear regression analysis techniques were used to explore how the ratings of the representations' similarity to textbook or classroom explanations were related to the student ratings of different characteristics. The similarity rating's relations to students' ratings of usefulness, salience and contiguity were positive and significant ($F(1, 24) = 6.5$, 6.0, and 10.6, respectively, $P < 0.05$). In other words, how similar a representation was to a textbook or classroom explanation was positively related to student ratings for how useful that representation was for their understanding of the algorithm, how well that representation pointed out the important features of the algorithm, and how well it was contiguous with (built upon) the other representations for that algorithm. For understandability and familiarity, the effect was also positive, but not significant. Interestingly, pleasure was the only student rating that was negatively affected by a representation's similarity to a textbook or classroom explanation, but the effect was not significant. Summarizing, how similar a representation was to a textbook or classroom explanation was related to what kind of rating a student gave to that representation, and the more a representation was similar to what they saw in their textbook or classroom, the higher the rating was.

A participant in the study talked about representations in a manner consistent with these results during a follow-up interview. He talked about representations as doing things the "class way" or being "teacher-like". According to him, the best representations had the pseudocode, a picture or visualization of the algorithm and a plain-text explanation using an example. He explained, "It is really the best combo. Teachers do that."

However, many students at the beginning of the study were turning in representations that did not look anything like the style he described. When asked what he thought when he was given the first assignment for the study, he replied, "We were upset. When someone just tells you to get creative ... it is hard for me to get like that." The students appeared to be anxious about turning in the first set of representations and complained about not being given enough direction. The authority was missing, leaving them to create their own idea of what would be a "good" representation. Over time, they converged on the conventions and styles used in the classroom or in the textbook.

One might argue that the students converged on a style that requires the least amount of work. However, while it is not known how much time each student spent on each representation, it is likely that creating a representation that is text-only takes less time than creating a representation that contains text and graphics, and the number of text-only representations decreased during the study. Therefore, it is unlikely that the convergence was driven by a desire to minimize the work involved.

4.2. Revising CAROUSEL

Based on what occurred during the pilot study, we revised CAROUSEL. We had two main goals in mind: *encourage divergence* and *lessen the effects of identity*. To encourage divergence, we changed one characteristic of representations that students rated, and changed the type of feedback students received and could give about each other's representations. To lessen the effects of identity, the system hid the identity of the student. Students used anonymous identifiers to interact with each other in the system, and the system did not reveal authorship.

In the first version of CAROUSEL, students rated representations on six characteristics, one of which was *contiguity* (How well did this representation connect with the other representations for this algorithm?). We suspected that having students rate this characteristic was unintentionally encouraging them to converge on a representational style. For the next study, students rated *originality* (How much does this representation differ from the other representations?), rather than *contiguity*, encouraging *diversity*, rather than *conformity*.

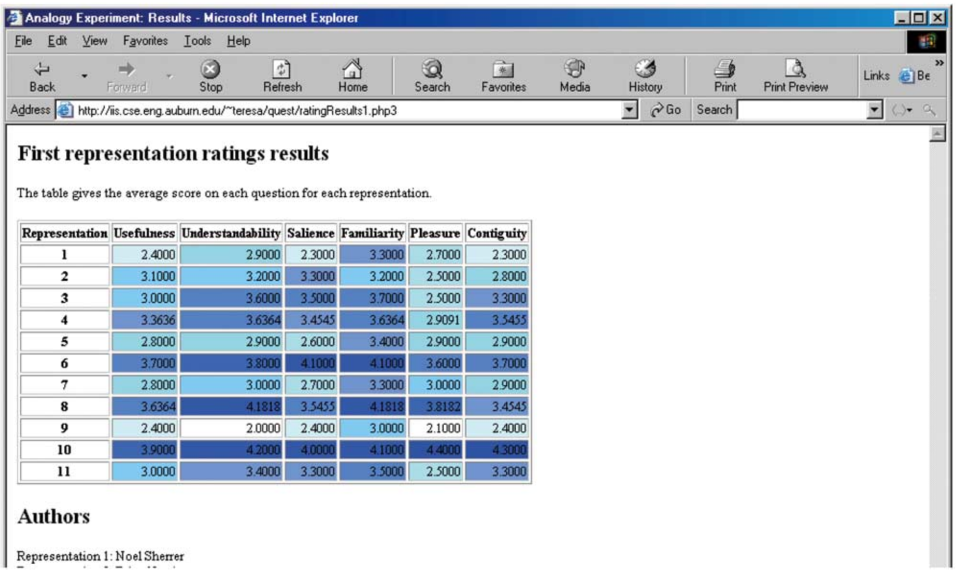
Also, the first version did not allow students to have a dialog about the representations. The only feedback that students received on how their representations were received was the average rating scores for all the characteristics, a numeric value, between 1 and 5 (Fig. 2). This led students to compete with and mimic those representations that had received high scores, which led to more conformity. In the second version of CAROUSEL, students did not see the average ratings given by the students. Instead they could see what kind of comments students posted about their representations and what comments were then attached to those comments (Fig. 3). Nested dialogues attached to representations and threads of conversation gave students a richer information source about how other students viewed and evaluated their work.

The first version of CAROUSEL revealed which student authored which representation, as well as the ratings, after the students were finished rating the representations (Fig. 2). This led the students to compete with their friends and other students. We suspected that some students were embarrassed, when their representations received a lower score than others, so it intensified the pressure to conform to the prevalent, well-rated style. The second version of the system tried to preserve anonymity throughout, although some students resisted this by embedding their names and identifiers in their representations.

4.3. Second CAROUSEL study

4.3.1. Method

Sixty students in an algorithm analysis course volunteered to participate. They created and evaluated representations for nine algorithms over 12 weeks. Three of the algorithms were the



Analogy Experiment: Results - Microsoft Internet Explorer

Address http://iis.cse.eng.auburn.edu/~teresa/quest/ratingResults1.php3

First representation ratings results

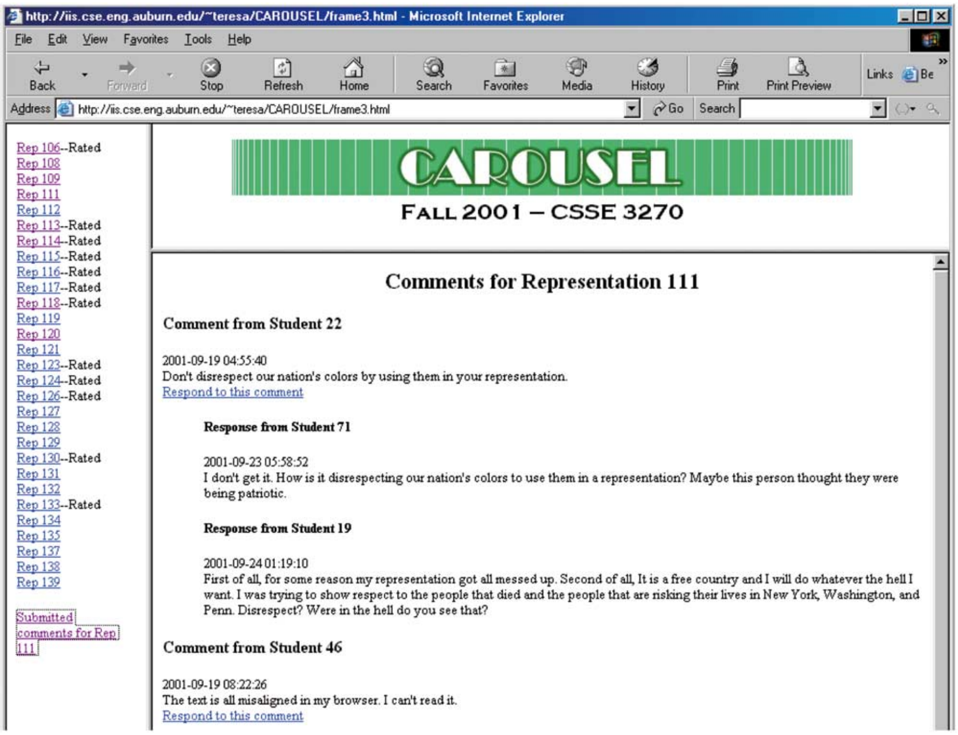
The table gives the average score on each question for each representation.

Representation	Usefulness	Understandability	Salience	Familiarity	Pleasure	Contiguity
1	2.4000	2.9000	2.3000	3.3000	2.7000	2.3000
2	3.1000	3.2000	3.3000	3.2000	2.5000	2.8000
3	3.0000	3.6000	3.5000	3.7000	2.5000	3.3000
4	3.3636	3.6364	3.4545	3.6364	2.9091	3.5455
5	2.8000	2.9000	2.6000	3.4000	2.9000	2.9000
6	3.7000	3.8000	4.1000	4.1000	3.6000	3.7000
7	2.8000	3.0000	2.7000	3.3000	3.0000	2.9000
8	3.6364	4.1818	3.5455	4.1818	3.8182	3.4545
9	2.4000	2.0000	2.4000	3.0000	2.1000	2.4000
10	3.9000	4.2000	4.0000	4.1000	4.4000	4.3000
11	3.0000	3.4000	3.3000	3.5000	2.5000	3.3000

Authors

Representation 1: Noel Sherrer

Fig. 2. The first version of CAROUSEL displayed the average ratings for the different characteristics that a particular representation received along with the author names.



http://iis.cse.eng.auburn.edu/~teresa/CAROUSEL/frame3.html - Microsoft Internet Explorer

Address http://iis.cse.eng.auburn.edu/~teresa/CAROUSEL/frame3.html

Rep 106--Rated
Rep 108
Rep 109
Rep 111
Rep 112
Rep 113--Rated
Rep 114--Rated
Rep 115--Rated
Rep 116--Rated
Rep 117--Rated
Rep 118--Rated
Rep 119
Rep 120
Rep 121
Rep 123--Rated
Rep 124--Rated
Rep 126--Rated
Rep 127
Rep 128
Rep 129
Rep 130--Rated
Rep 131
Rep 132
Rep 133--Rated
Rep 134
Rep 135
Rep 137
Rep 138
Rep 139

Submitted comments for Rep 111

Comments for Representation 111

Comment from Student 22

2001-09-19 04:55:40
Don't disrespect our nation's colors by using them in your representation.
Respond to this comment

Response from Student 71

2001-09-23 05:58:52
I don't get it. How is it disrespecting our nation's colors to use them in a representation? Maybe this person thought they were being patriotic.

Response from Student 19

2001-09-24 01:19:10
First of all, for some reason my representation got all messed up. Second of all, It is a free country and I will do whatever the hell I want. I was trying to show respect to the people that died and the people that are risking their lives in New York, Washington, and Penn. Disrespect? Were in the hell do you see that?

Comment from Student 46

2001-09-19 08:22:26
The text is all misaligned in my browser. I can't read it.
Respond to this comment

Fig. 3. The second version of CAROUSEL displayed the comments made by other students or the instructor for a particular representation.

same as those in the pilot study: the algorithm for generating the Fibonacci number series, the Selection Sort algorithm and the Merge Sort algorithm. The other six algorithms were an algorithm for exponentiation, the algorithm for inserting an element into a Binary Search Tree, the Leftist Heap Merge algorithm, the Quick Sort algorithm, the Disjoint Set Find with Path Compression algorithm, and the Depth First Search algorithm. The first three algorithms were selected since they were used in the previous study. The others were chosen because they were recursive algorithms for solving a variety of different problems, and undergraduate computer-science students find recursion a difficult concept to master.

A pretest was used to test prior knowledge of each algorithm, and an identical posttest was used to evaluate student learning after the students had created and evaluated the representations related to that algorithm. The pretest was given at the time when the students were provided with directions to begin creating a representation for a certain algorithm, and the posttest was given a week after students began commenting on a particular representation, immediately after the extra-credit assignment for a particular algorithm had ended.

After the representations for an algorithm were collected, the students could begin evaluating the representations. Their comments were automatically posted with a representation, and students could attach comments to comments allowing dialogs to ensue, which were tied to a particular representation or comment. Submitting a comment to a representation was voluntary.

The students were given extra credit in their course for participating, based on how much they participated. They could choose to only take the pretest and the posttest, or to also create and/or evaluate representations. As in the other studies, they were told their performance in the study would not affect the extra credit they received or their course grade in any way, and the instructor of the course would not know about their performance in the study.

4.3.2. Results and discussion

The representations in this study converged less on a type, style and choice of topic than in the pilot study, which implies that the revisions to the system worked. There was not a significant difference between the media the students chose to work with during each assignment, and certainly no trend towards a particular style, as in the pilot study. Students seemed to stick with the media they originally chose to work with throughout the study. Sixty percent of the representations constructed by students walked through an example of the algorithm working on a particular data set. However the number of representations that illustrated stepping through the algorithm with an example did not significantly change over the course of the study. So students did not converge towards such a style, as was the case in the pilot study. Instead, they started creating representations with this style from the very beginning.

Metaphors outside what would normally be seen in a textbook or class did decrease over time. There was a significant difference in the number of representations that contained these metaphors over the assignments ($\chi^2(8, N=206)=25.4$, $P=0.001$). Table 1 shows the decreasing trend in the percentage of representations that contained unique metaphors for each assignment.

All the representations in the study were rated by one of the researchers on a scale of 1–5, with 1 being a rating for representations that are least like a textbook or classroom explanation and 5 being a rating for representations that are most like a textbook or classroom explanation, as was done in the first study. There was a significant difference in this similarity rating assigned to each representation between the assignments ($\chi^2(1, N=206)=62.1$, $P=0.001$), but there was

Table 1
This table shows the percentage of representations that contained unique metaphors for each algorithm assignment

Assignment	1	2	3	4	5	6	7	8	9
No metaphor	50%	62%	79%	90%	86%	85%	90%	95%	81%
Metaphor	50%	38%	21%	10%	14%	15%	10%	5%	19%

not a trend toward the representations becoming more similar to the representations used in class (Table 2). These ratings did not increase over time with each new algorithm. The trend shows the students developing a style that is not far from the style used in their course but not particularly close either.

The average of all the ratings the students gave each representation is not significantly positively related to the rating of how similar that representation is to a textbook or classroom explanation (unlike the first study). Multiple linear regression analysis techniques were used to explore how the ratings of the representations' similarity to textbook or classroom explanations were related to the student ratings of different characteristics. In the first CAROUSEL study, the similarity rating's relations to students' ratings of usefulness, salience and contiguity were positive and significant. In this study, the similarity ratings' relation to students' ratings of usefulness, understandability and salience were positive and significant ($F(1, 205)=4.56$, 5.25 and 9.65, respectively, $P<0.05$). In other words, student ratings of how useful the representation is, how understandable it is, and how well it points out the important points of the algorithm were positively related to how similar that representation was to their classroom and textbook conventions. Familiarity is positively related, but the effect was not significant. The similarity ratings' relation to students' ratings of pleasure and originality were negative and significant ($F(1, 205)=4.09$ and 16.6, respectively, $P<.05$). Students rated representations higher in pleasure and originality, if those differed from their classroom conventions. It seems authoritative styles and conventions might still have affected how students evaluated representations. But since they did not see these evaluations, the ratings received by representations probably affected the style of representations students created less than in the first study.

The student representations in the second study did not just use more styles and conventions; they actually represented different aspects of algorithms. In the first study, most representations were a walkthrough of an algorithm, giving an example of a data set and showing how it would

Table 2
This table shows the percentage of representations that received a particular similarity rating from the experimenter for each assignment

Rating	Assignment								
	1	2	3	4	5	6	7	8	9
1	34%	38%	24%	14%	23%	15%	10%	5%	19%
2	16%	9%	28%	24%	4%	20%	15%	10%	29%
3	25%	10%	10%	34%	32%	25%	35%	40%	38%
4	19%	5%	31%	14%	32%	35%	35%	45%	14%
5	6%	38%	7%	14%	9%	5%	5%	0%	0%

change over time as the algorithm operated on it. It focused on the execution of pseudocode. Walkthroughs were prevalent in the second study as well; 60% of the representations used this type of representation. However, there was not a convergence to this style over time, and there was no significant difference in the number of such representations across the assignments. Some of the remaining representations focused on aspects of the algorithm that had not been represented at all in the first study, such as representing the pseudocode itself with graphical representations, representing efficiency through interactive comparisons with different algorithms, representing the main ideas and reasoning behind the algorithm, and representing the results of execution.

Unlike the first study, students were given a pretest (immediately before each algorithm assignment) and a posttest (immediately after the assignment), and learning was measured as the difference between these scores for each algorithm. This was done because these students were in a class that covered these concepts and it was difficult to prevent them from learning about the algorithm in class or from other sources over the 12 weeks. However, we ensured that each assignment was completed before the corresponding algorithm was discussed in class. The pretest and posttest scores were not revealed to the students. There was a significant difference between whether someone had created a representation or not and the normalized posttest scores ($F(1, 327) = 14.4$, $P < 0.001$) and the normalized learning scores ($F(1, 327) = 3.63$, $P = 0.058$). The scores were normalized by dividing the raw score by the maximum score attained by any student on a test for a particular algorithm. In both cases, the students who created and evaluated the representations had higher scores than the students who only evaluated the representations. There was no control group in this study, but students could choose whether to evaluate representations or to create and evaluate representations, making the above comparison possible.

Overall, the changes to CAROUSEL had positive effects. Students produced different styles of representations and did not converge on a single style. They also represented different aspects of algorithms. It appears they felt less pressure to conform to some sort of authoritative norm, and felt that creating a different representation than the norm was appreciated. With the revised version of CAROUSEL, students could benefit from considering multiple perspectives through multiple representations and obtain a broader understanding of the algorithms involved.

However, the fact that the student group was larger and drawn from a more advanced computer-science course than the student group in the previous study probably also played a part in the results, but it is difficult to quantify and separate the effect of these differences. These differences also make it difficult to answer the question of whether the enhanced diversity of representations influenced learning outcomes by comparing test scores from the two studies.

5. Recommendations

Based on our results, we present a set of recommendations for CSCL systems. These recommendations are meant to aid CSCL system developers create systems that improve collaborative learning and lessen the negative effects of authority in the classroom. The four main recommendations are to allow students to both work alone and together, encourage divergence, lessen the effects of identity, and to explicitly rewrite the classroom contract.

5.1. Require students to both work alone and together

Engaging students in both dialog and monologue is critical for effective collaborative learning (Hoadley & Enyedy, 1999). Monologue does not depend on the context, social cues and interaction to communicate and interact with ideas, whereas dialogue has distributed control of the conversation among participants and involves interaction, common construction and sharing of ideas. Students need to produce monologues of their own understanding (Chi, de Leeuw, Chiu, & LaVancher, 1994). However, making one's initial understanding available for further inspection and dialog is also critical for active learning.

Certain CSCL systems seek to balance student monologue and dialogue. The CoWeb system has students display individual work on web pages and then allows others to edit that work to create a dialogue about their understanding (Guzdial & Kehoe, 1998). CSILE (Computer-Supported Intentional Learning) supports students in collaborative knowledge building activities by creating a shared database that contains student representations of their knowledge. Students can author their own ideas and record them in the database, but their knowledge is linked to the knowledge already in the database, the social knowledge repository. The system promotes both individual reflection and group interaction with the knowledge base (Scardamalia & Bereiter, 1991). Hoadley and Enyedy (1999) used two different complimentary tools, SpeakEasy and SenseMaker, to support monologue and dialogue: SpeakEasy helps students have structured discussions, and SenseMaker helps students create an overview and integrate ideas.

CAROUSEL has students engage in individual work prior to engaging in dialog. One form of this dialog is as comments attached to representations by students who inspect and evaluate them. But a more significant dialog is at work over time and across subsequent representation assignments. Students develop individual and group styles, engage in conversations about their common experiences as computer-science students in the class, and seem to develop an understanding about *how* to create an expository representation that will be useful to the other students in the class, rather than one that is just similar to the style authority figures in their course use.

5.2. Encourage divergence

Students need to be explicitly encouraged to diverge from cultural norms and disagree with each other, especially at the early learning stages. CSCL systems and teachers need to challenge students who believe that one representation can and does represent all aspects of a concept. Instead, students need to be encouraged to look for differences between representations and see the aspects that are obscured and hidden by any particular representation as well as aspects that are highlighted. Allowing students to work alone initially will likely encourage more divergence, but it alone will not prevent them from picking one representation among the many and using that one to the exclusion of others during collaborative learning. Integration and consideration of differences should therefore be explicitly encouraged.

CAROUSEL was created with the idea that students will consider multiple representations and realize their partiality, because each participant creates their own unique representation and displays it. However, over time, in the pilot study, they became less unique, because students were converging on cultural norms. Steps taken in the revised version of CAROUSEL alleviated many of these problems. With the revised CAROUSEL students created individual styles of representations and represented different aspects of the algorithm. In the second study with CAROUSEL, students not only seemed to realize that one representation does not represent all aspects of an algorithm, but also the benefit in creating representations that were diverse.

5.3. *Lessen effects of identity*

Certain students in a class have more authority than others. As students reported in their interviews, students start courses knowing which of their peers are more likely to receive good grades and understand the material. The representations or arguments of these students may carry more weight than those of others, encouraging convergence. So it is important in the early stages of a collaborative learning activity that student authors remain anonymous to lessen the effects of identity on convergence and engagement.

In the first version of CAROUSEL, the authors of the representations were identified as soon as the evaluations were finished. As a student in the pilot study reported, the students checked on their ratings and saw how they compared to individuals in the class. They converged on representational norms that they saw as authoritative in the classroom.

Therefore, the revised CAROUSEL tried to preserve the anonymity of the authors. Still, often students were sneaking their names, initials, or email addresses into their representations. They wanted to be able to be associated with the work they had done, especially if they were proud of it. Individual formatting and graphical styles were created and adhered to in the second study, making authors immediately recognizable. Still, the students competed less, since the Web site only displayed the comments of other students to the work, rather than the ratings' averages. Students created individual styles and topics of representations for the different assignments and felt less pressure to conform, when it was their choice whether to have their identity revealed or not.

5.4. *Rewrite the classroom contract*

The classroom contract has to be explicitly rewritten for collaborative learning to be successful. Authority should be reassigned, based on input and agreement of both the teacher and students. Power and control does not reside in either the teacher or students, but instead is created between them. "A more dialectical and less functionalist perspective considers power and control as dynamic processes that are constructed and negotiated between teacher and students. ... It is through teacher-student communication that power is developed, attributed and maintained" (Staton, 1992, p. 173). Authority cannot be successfully assigned by a computer system or even a social system such as the school system without the agreement of the participants. For collaborative learning to be successful, the participants must make explicit the new terms and arrangement of authority.

For students and teachers to agree to a collaborative learning activity, it must be clear to both parties what the intended roles of the participants will be and what benefits one will receive from the additional responsibility and authority. One student who had used CAROUSEL in the pilot study said he felt that it needed to be clearer how the study was related to his class and how he was benefiting from it. "Tie the representation assignment with the class. ... It should have been more tied with our assignments every week," he suggested.

Gifford and Enyedy (1999) argue that CSCL environments should be designed by looking at the activities they are supposed to support. They argue that many CSCL systems do not fit with nor change the basic activities of the classroom, and therefore have little effect on the learning of students. They propose that CSCL systems should focus on supporting activities where learners and the teacher plan and participate in learning activities. CSCL systems have to be integrated into the social activities in the classroom. The best learning environment is one that can flexibly adapt to the learning activities already negotiated in the classroom.

6. Conclusion

A major force affecting classroom communication and social interaction is authority. Authority is the power given to certain people, objects, representations or ideas to affect thought, opinions and behavior. Authority was instrumental in how college students used, created or evaluated representations in the first two studies described in this paper. In the first study, students converged on an authoritative example provided by the instructor, to the exclusion of other explanatory representations that were available to them in a lecture and their textbook, and ignored the limitations of that representation while struggling to answer questions posed to them. The students' perception of the teacher as the authority figure in the classroom discouraged critical analysis and questioning of representations. In the second study, students gave high ratings to expository representations created by their peers that were similar in style to those found in the textbook and classroom lectures, resulting in a convergence over time toward that style of representation. In both studies, instead of evaluating a representation by looking at its content and how well that is expressed, judgments by students were based on how much time their instructor invested into a representation or how well a representation fit with the style normally used by textbooks and in lectures. This discouraged students from expressing original viewpoints of the concept, and instead resulted in them looking at the same aspects of the concept in the same way. In the third study, however, students were encouraged to diverge and the pressure to conform was less. This had a positive effect on the diversity of the representations created. Students were better able to express original viewpoints and represented different aspects of the concept in different ways.

Some argue that collaboration necessarily leads to a diversity of ideas. "It is more likely in a group that the limits of single interpretations or representations will be counteracted by alternative interpretations" (Feltovich et al., 1996, p. 36). However, how authority is assigned, recognized and resisted greatly affect whether this will happen. Instead of alternative interpretations arising in a collaborative learning setting, students may work to reinforce biases, to silence those with differing opinions and to reinforce a single view of looking at the concept. The students in our first study might have been better off if they were working alone rather than collaboratively. Much of the literature on authority is derived from investigations of K-12 students. There is a need to explore the role of authority in college classrooms, as the different dynamics of higher education may lead to different conclusions. The work reported in this paper is a small step in this direction.

Design of CSCL systems needs to consider how to manage and distribute authority. By changing the perception and assignment of authority, such systems must encourage students to *diverge* *before converging*, and facilitate critical analyses of different viewpoints and representations. This can be accomplished by explicitly changing the classroom contract, and having students do independent thinking as well as engaging in dialogic activities where anonymity of authorship is preserved at least initially.

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