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DESIGNING FOR DIVERGENCE

Abstract. Constructionist theories hold that learning will be deeper if students develop and share their own diverse understandings of a concept. College students are immersed in a community with its social norms, learning practices and an understanding of authority and the classroom contract. This situation makes it difficult for the students to have diverse understandings of a concept. This paper addresses how this affects the nature and diversity of representations students create for collaborative learning, and their perceptions of the quality of representations created by their peers. We redesigned and deployed a CSCL system with the goals of facilitating learning by leveraging students' current collaborative learning practices and changing their perceptions of authority. We present summary results from two studies, which are part of an ongoing research program investigating these questions. In prior research we found that students have a strong sense of which style of representation is authoritative, and that this can lead to premature convergence and the suppression of alternative viewpoints. Results from the current studies indicate that creating, sharing and evaluating representations through a CSCL system improve learning. Furthermore, careful design of the CSCL system and learning activities can indeed lead to an increase in the diversity of created representations, avoiding some problems we saw previously with early convergence. However, authority still influences representational creation and evaluation. We revisit our design goals and recommendations in light of these results.

1. INTRODUCTION

Constructionist theories hold that learning will be deeper if students develop and share their own diverse understandings of a concept. Computer-supported collaborative learning (CSCL) systems that encourage students to develop and exhibit explanations and artefacts (e.g., CoWeb: Guzdial, Rick & Kehoe, 2001) or engage in discourse (e.g. CSILE: Scardamalia & Bereiter, 1991) embody this idea. However, learners, especially college students, are already immersed in a community with its social norms, learning practices and understanding of authority. How does this affect the nature and diversity of representations they create during collaborative learning, and their perceptions of the quality of such artefacts constructed by their peers? How can one sensitise CSCL system design to the natural learning practices of students and their perceptions of authority, in order to promote representational diversity instead of convergence? We are investigating these questions in an ongoing research program.

In an earlier paper we reported studies of computer-science undergraduate students engaged in learning algorithms, which revealed convergence and its detrimental effects (Hübscher-Younger & Narayanan, 2002). We found authority is instrumental to how students use, create and evaluate representations. As a result of this finding, we created a system for supporting web-based collaborative learning called CAROUSEL (Collaborative Algorithm Representations Of Undergraduates for Self-Enhanced Learning) to support students sharing and evaluating their own representations of algorithms. Students used this system to learn algorithms through a set of activities. First, they individually created explanatory representations of

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algorithms using tools of their choice, such as Flash, Javascript and html. They uploaded these representations to CAROUSEL, which displayed them on a web site. Each student then accessed everyone else's representations through CAROUSEL, and evaluated them by commenting on them and rating six representational characteristics using a five-point Likert scale. These characteristics are:

1. *Usefulness* (How central was this representation to your understanding of the algorithm?)
2. *Understandability* (How easy was this representation to understand?)
3. *Salience* (How well did this representation point out the important features of the algorithm?)
4. *Familiarity* (How familiar were you with the content of the representation?)
5. *Pleasure* (How much did you enjoy the way this representation communicated the algorithm?)
6. *Originality* (How much did this representation differ from the other representations?)

Architectural and interface details of CAROUSEL may be found in another paper (Hübscher-Younger & Narayanan, 2003).

We then studied how a small group of students used this system, especially how their representations changed over time. The type and style of representations converged over the course of five weeks. At the beginning of the study, many different types of representations of algorithms were created, including ones with 3-D animation, sound and stories. However, by the end of the study, most of the representations were graphics and text representations, without metaphors and analogy. These were similar to the representations one would find in the lectures students attended and in their textbook. Rather than students coming from diverse points of view and converging on a shared understanding, they already had a shared understanding, which worked to reinforce biases and limit their exploration of multiple representations of a concept.

These students were already members of a community of practice, the community of undergraduate computer-science students, and, as a result, had discourse norms and methods of understanding concepts. We found the problem was not with students developing a shared understanding, but with students not questioning that understanding. Using the features of a productive collaborative learning discussion defined by Hoadley (2002), we discovered these students' discussions involved inclusiveness and externalisation of models of the domain, but differentiation, linking and selection were not occurring. Old models did not lead to considerably new ones, and therefore, no consideration was given to the representations' coherence or explanatory power.

Students converged on an authoritative representation or representational style, despite the limitations of that representation or style, which discouraged the critical analysis and questioning of representations. Students looked at the same aspects of the concept in the same way. Collaborative activities reinforced the authority assigned to representations and representation styles, leading to a premature converging on ideas, rather than a diversification of ideas. We observed how students working together reinforced biases, silenced those with different opinions and reinforced a single way of looking at a concept.

From our observations, we suggested methods to manage and distribute authority to avoid students converging on a way of understanding a concept or method of representation too early. These recommendations were reported in (Hübscher-Younger & Narayanan, 2002), and are summarized in the following paragraphs.

First, students should participate in both dialog and monologue for effective collaborative learning. A student needs a chance to reflect on concepts by herself initially, as well as a chance to share that understanding with others.

Second, students need to be explicitly encouraged to diverge from cultural norms and disagree with one another, especially in the early learning stages. CSCL systems and instructors need to challenge students who believe that one representation can, and does, represent all aspects of a concept. Students need to be encouraged to look for differences between representations and realize certain aspects of a concept can be obscured by any particular representation.

Third, the effects of identity need to be lessened within the system. Certain students in a class have more authority than others. As students reported in their interviews, they often start college classes believing they know 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 and the silencing of differences. It is important in a collaborative learning activity's early stages that student authors remain anonymous.

Finally, the classroom contract has to be explicitly rewritten. 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 the new terms and arrangement of authority explicit.

CAROUSEL was subsequently redesigned based on these recommendations. In a study reported earlier (Hübscher-Younger & Narayanan, 2002) – henceforth referred to as the *previous study* – we used *contiguity* (how well did this representation connect with the other representations for this algorithm?) as the sixth characteristic. We suspected that this characteristic was unintentionally encouraging students to converge on a single representational style. As a result, contiguity was replaced with originality. Another system feature that might have encouraged convergence was the display of the mean rating scores a representation received on each characteristic. We believed this compelled students to mimic styles that received high average scores. The system was therefore revised to hide this information, but allowing students to post public comments on the representations. Finally, representations and comments were made anonymous. Unlike with the previous CAROUSEL version, the students were kept anonymous, not just as evaluators of representations, but also as creators of representations.

This paper discusses the results of two new and larger-scale studies using the redesigned CAROUSEL. The changes in the design led to desired effects: students did not converge on a media or authoritative style as they had in the previous study, and they were also representing different aspects of the algorithm. The changes also led to some unexpected effects, such as students trying to entertain and impress each other, undermining efforts to preserve anonymity, and arguing in their discussions over superficial aspects of representations unrelated to content. Also, although the strong convergence effect we saw in the previous study was not seen in the present two studies, authority and classroom practices still affected the representations created, especially in the choice of metaphors and content of the representations.

2. STUDYING CAROUSEL USE

Both studies recruited volunteers from an introductory algorithms class, who were given extra credit for completing assignments covering different algorithms. The first study involved 60 volunteers in fall semester of 2001 and the second involved 43 students in spring semester of 2002. Each assignment included these phases: taking a pretest, individually creating and sharing explanatory representations after studying a step-wise description of an algorithm (called pseudocode), commenting on and rating representations of others, and taking a posttest. Students could choose to only take the two tests, take the tests and evaluate others' representations, or take the tests, create and share their own representations and evaluate those of others. They were given variable amounts of extra credit based on how many assignments they completed and how many phases of each assignment they completed.

Each assignment took two weeks. Students had one week to study an algorithm and create representations and another week to view others' representations and evaluate them. The first study occurred over 12 weeks with nine different algorithm assignments: Fibonacci Number Series, Exponentiation, Inserting into a Binary Search Tree, Merging Leftist Heaps, Selection Sort, Merge Sort, Quick Sort, Find with Path Compression for a Disjoint Set and Depth First Search. The activities overlapped, so that often they were creating one new representation and reviewing representations from the previous assignment in the same week.

The schedule for the second study was condensed due to external circumstances, and four algorithms were covered in four weeks. The activities for the four algorithms overlapped, so that often students were creating two new representations and reviewing two representations from previous assignments in the same week. Algorithms covered were: Find with Path Compression for a Disjoint Set, Dijkstra's Shortest Path, Creating Huffman's Codes and Depth First Search.

Overall results implied that the activities of creating, sharing and evaluating algorithm representations aided learning. The students improved their score from pretest to posttest by 30% on average in the first study and by 40% on average in the second. Students who created representations had higher scores than those who did not (i.e. those who only evaluated and commented on others' representations). The means for the normalized posttest scores for the students who did not create a representation were 46% and 48% in studies one and two respectively, while for the students who did create one these scores were 57% and 62%. The means for the normalized learning scores for the students who did not create a representation were 25% and 26%, whereas the scores of those who did create one were 31% and 40%. The learning score was computed as the difference between posttest and pretest scores. Scores were normalized by dividing the raw scores by the maximum score attained by any student on a test for a particular algorithm.

In both studies, we found a significant difference between the normalized posttest scores ($F(1,327)=14.4$, $p<0.001$ and $F(1,94)=5.44$, $p=0.02$ respectively) and the normalized learning scores ($F(1,327)=3.63$, $p=0.058$, $F(1,94)=4.43$, $p=0.04$) of those who had, and those who had not, created representations. The degrees of freedom in the ANOVA reflect the combined activities over all the assignments, but not all students participated in all the assignments. Moreover, some students completed only part of the activities or phases of a certain assignment.

In the first study, the average combined rating score (the average of ratings for a representation across all six rating characteristics) was significantly positively correlated to the normalized learning score (($r=0.153$, $p<0.01$)($F(1, 327)=5.43$, $p=0.02$)). This implied that the quality of the representation created by a student positively influenced how much he or she learned from this activity.

3. AVOIDING CONVERGENCE

Student-created representations in both studies converged less on a type, style and choice of topic than in the previous study, which indicated that CAROUSEL redesign had the desired effect. The experimenter rated the level of media use for each representation on a scale of 1 to 4, with 1 being the use of only text, 2 being the use of graphics and text, 3 being the use of graphics, text, sound and/or animation and 4 being the use of all of the previously mentioned plus hypermedia and/or additional interactive components. In the previous study, students converged over time on a style that used graphics and text, media level 2. In the two studies reported here, 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. Students stayed with the media they chose to work with throughout each study.

In these two studies, the student ratings of all representational characteristics were significantly affected ($p<0.001$) by the type of media used, as measured by the media ratings. Adding graphics to text improved the ratings of all characteristics. Adding sound and/or animation to a representation improved the pleasure and originality ratings more than 0.5 points and the understandability rating 0.1 point in the first study, and improved the ratings of all characteristics in the second study. Adding hypermedia or interactive components improved the ratings of all characteristics, except pleasure and originality, in the first study. But in the second study, adding hypermedia or interactive components decreased the ratings of all characteristics. In other words, adding graphics to text always led to increased ratings. Adding sound and/or animation always led to more pleasurable and original representations. Adding hypermedia or interactive components did not necessarily increase ratings, and sometimes led to decreased ratings.

In the previous study we found that students converged toward media level 2. These students were shown the average scores each representation received for each representation characteristic, and we believed this influenced their choice of what type of representation to create over time. The average ratings for each of the six characteristics given to different representations of varying media types in the current studies were similar to those of the previous study. This suggests that the students viewed and evaluated the representations similarly. However, while there was still a decreasing rate of return (in the form of lower rating scores) for adding more complicated media to a representation, this did not affect the type of representations students created over time. In other words, the students did not converge to a particular media choice in the current studies, despite their evaluations of representations being similar to the previous study.

All the representations were rated by the experimenter on a scale of 1 to 5, with 1 assigned to representations that were least like a conventional (textbook or classroom style) explanation, and 5 assigned to representations that were most like a conventional explanation. In the second study, there was not a significant difference in the rating given to each representation for similarity between the assignments, but in the first study there was (χ^2(32, N=206)=62.4, p=0.001). However, there was no trend toward the representations becoming more similar to conventional representations. These ratings did not increase over time with each new algorithm. Unlike in the previous study, students did not converge toward a textbook-type representational style. This is, however, not a sign of all participants creating divergent representations. A large number of representations (60% in the first and 70% in the second study) were of a "walkthrough" style, in which text and graphics are used to explain how algorithms operate on data. This is also the style used in the textbook and the instructor's lectures.

In the previous study, the average of all the ratings students gave each representation was significantly related to the experimenter's rating of how similar that representation was to a conventional explanation. In the present two studies, these two factors were not significantly related. Multiple linear regression analysis techniques were used to explore how the experimenter's ratings of the representations' similarity to conventional explanations were related to the average student ratings of different characteristics. In the first 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 a representation was, how understandable it was, and how well it pointed out the important aspects of the algorithm were positively influenced by how similar that representation was to their classroom and textbook conventions. The similarity ratings' relation to students' ratings of pleasure and originality were negative and significant ($F(1,205)$= 4.09 and 16.6 respectively, $p<0.05$). Students rated a representation higher in pleasure and originality if it differed from their classroom conventions. It appears that in the first study authoritative styles and conventions still had an influence on how students rated representations, but since they did not see the mean rating scores due to a CAROUSEL redesign, the authoritative style had less effect on the representations they created. In the second study, only the similarity ratings' relation to students' rating of originality was significant ($F(1, 65)$=8.72, $p=0.004$), but the relation was negative. The higher the similarity rating was, the lower the students rated the originality of the representation.

4. AUTHORITY AND UNINTENDED EFFECTS

Authority and classroom norms still had an effect on the type of representations created. In the previous study, students' representations converged on a particular style, which involved a walkthrough of an algorithm on a data set showing how the data changed over time as the algorithm executed. This style of representation focuses on the execution of pseudocode. Students perceive it as having high authority, since it is commonly found in their courses' textbook and lectures. This style was still prevalent in the two studies reported here. It was 60% of the first study's representations and 70% of the second study's representations. There was not a convergence toward this style, however. In the two studies there was not a significant difference in the number of walkthrough representations over all the assignments given. Whether a representation used this style had a significant effect on the student ratings of all characteristics as well ($p<0.0001$). Walking through an example improved the student rating for every characteristic. Thus, the most authoritative style had a strong influence on the representations students created and how they rated others' representations.

In the first study, there was a significant difference in the number of representations that contained novel metaphors (outside what would normally be seen in a textbook or class) over the assignments ($\chi^2(8, N=206)=25.4, p=0.001$). The use of such metaphors decreased over time, a convergence effect. In the second study, there was not a significant difference over the assignments in the number of representations that contained such metaphors. However, the number of representations that contained this type of metaphor was small, only 15% of the representations. The students did not converge on an authoritative style; instead, most of them started with one! We analysed whether the existence of a novel metaphor in a representation affected its ratings. In the first study, the metaphoric content was significantly related to the student ratings of pleasure and originality ($F(1, 205)= 8.37$ and 23.38, $p<0.005$, respectively). In both cases the relation was positive, so the existence of a novel metaphor led students to find the representation more enjoyable and original. In the second study, however, metaphoric content was significantly and negatively related to the students' ratings of all representational characteristics ($p<0.0001$). In both cases using novel metaphors had a strong influence on how students rated representations.

Students did differ from the previous study, though, in what they chose to represent; they represented different aspects of the algorithm. Students in the previous study represented only the operations of an algorithm on a data set over time. Students in the first study also did this, but they were additionally illustrating the pseudocode using pictures, representing efficiency through interactive comparisons of different algorithms, representing the main ideas and reasoning behind an algorithm, and representing the results of execution. Students in the second study represented even more aspects: the application of the algorithm to real-world problems and discussions of the algorithm's creator and history. These differences can be partly attributable to authority. The instructor of the course from which students in the second study were drawn had her class regularly think of how algorithms might be applied to realistic problems and what the benefits and drawbacks of using different algorithms were.

The redesign of CAROUSEL also led to some unexpected effects. The revised system had students rate each representation's originality to encourage them to diverge. Resulting representations often included content that made them original and creative, but the originality was not necessarily related to the concept being discussed. For instance, a representation of the algorithm for creating Huffman's codes included a picture and biography of the algorithm's inventor, a description of the algorithm working on a textual input, a description of how greedy algorithms work, a quote from Donald Trump about greed, and a video clip from the cartoon Pinky and the Brain about taking over the world. Sometimes student feedback in the form of comments, instead of focusing on the explanatory content of representations, dwelled on superficial aspects such as the colour scheme used in representations. CAROUSEL was redesigned to preserve anonymity by hiding which student created which representation. Nevertheless, some students worked around the system to retain authorship. First, some students posted their names and email addresses as part of the representation. When they were told not to do this, they found other means to preserve identity such as placing an online nickname at the bottom of representations.

5. INFORMING DESIGN

Some argue that the challenges of CSCL are to engender learning through building a shared understanding of the problem and creating a culture of inquiry and collaboration. The biggest challenges that our studies revealed were not these. These students already existed in a culture of inquiry and collaboration. They had a shared understanding of the problem, but, unfortunately, they also shared an approach to the problem and an understanding of what makes an appropriate solution, before they had explored enough alternatives to lead to a rich, or even adequate, understanding. Our original recommendations (Hübscher-Younger & Narayanan, 2002) were to allow students to both work alone and together, to encourage divergence, to lessen effects of identity and to rewrite the classroom contract. These are revisited below in light of the two studies reported here.

Allow students to work both alone and together. Participating in both dialog and monologue is critical for effective collaborative learning (Hoadley & Enyedy, 1999). We balance monologue and dialog with CAROUSEL: students first work independently to create their representations of algorithms and then work together through commenting on and rating the representations. While we believe that evaluating representations to provide scores for its characteristics can lead students to critically examine a representation as well as the concept represented, engaging in on-line commenting and discussions may not necessarily provide learning benefits. Comments are often focused on surface characteristics of the representations, rather than on their semantic content. More needs to be done to promote reflection, critical thought and comparative analyses of multiple representations, so that students develop new insights. Seeding discussion of the study topics as well as guiding it along critical and analytical directions by an authority figure, such as the instructor or teaching assistant, are potential solutions to this problem.

Encourage divergence. Students need to be explicitly encouraged to diverge from cultural norms and disagree with each other, especially at the early learning stages. We were successful in this aspect. The changes to the CAROUSEL system did lead to less convergence and a greater diversity of representations compared to its earlier version. However, authoritative conventions still had a large impact on the representations created.

Lessen effects of identity. To encourage students to be more effective and frequent participators in CSCL, we recommended lessening the effects of identity. We did this in CAROUSEL by maintaining anonymity of representation authors and evaluators. When we found students inserting their personal information, we actively discouraged it by pointing out that a representation with identifying information might not qualify for extra credit. Still, some students ignored these admonitions and found ways to work around this restriction. Taking ownership and displaying the results of effort are important aspects of constructionism. Students do put more effort into something that displays their identity. However, it can also have unintended consequences, such as the effort going into entertaining and impressing colleagues, rather than focusing on the concept to be learned.

Rewrite the classroom contract. For collaborative learning to be successful, the classroom contract has to be explicitly rewritten. Authority should be reassigned, based on input and agreement of both the teacher and students. Authority cannot be successfully assigned by a CSCL system without the agreement of the participants. In the present studies, the experimenter made clear that the students were expected to assume authority in this activity and made efforts to promote student acceptance. First, the experimenter took into account student suggestions for specific algorithms to be covered. Second, it was made clear to the participants that they had full authority in decisions regarding the content, media and style of the representations they constructed. Third, the activity benefited students by providing them with extra credit and thus improving their course standing. Fourth, the representations they created covered the algorithms they needed to learn for their course, so they felt they would receive a secondary benefit in the form of improved scores on regular course exams. Overall, students exerted more authority as well as took more ownership for the various activities of each assignment in these two studies than they had in the previous study.

6. CONCLUSION

Constructionist theories of learning hold that learning will be deeper if students develop and share their own diverse understandings of a concept. However, both traditional methods of instruction, such as lectures, and modern techniques, such as multimedia explanations and visualizations, emphasize a transmission model of learning. If learners passively acquire their knowledge from few authoritative representations, it is unlikely that they will develop a rich and diverse understanding.

CSCL addresses this problem, by developing systems and approaches that encourage students to construct and share representations of their own understanding. While this holds the promise of enriching the knowledge developed by a learning community, collaborating learners can prematurely converge on a few representations based on notions of authority and classroom contract.

In prior research with undergraduate students of computer science, we investigated their learning strategies and how they used a CSCL system called CAROUSEL that allowed them to exhibit, evaluate and discuss their own representations of algorithms. We found that students naturally tend to work together to understand difficult concepts such as algorithms, that they bring to their learning activities both a strong sense of which style of representations of a subject matter is authoritative, and that this can lead to premature convergence toward a certain kind of explanation and suppression of alternative viewpoints in their discourse. In this paper we discussed two new and larger-scale studies with a redesigned CAROUSEL. Results from these suggest that creating, sharing and evaluating representations improve learning. Furthermore, intentional system design choices can lead to richer and more diverse representations, which in turn affect student perceptions of representational quality. However, it is difficult to completely eliminate the influence of authority on representational creation and evaluation.

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