Design Collaboration in a Distributed Environment

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Abstract - **In engineering design classes, much of the learning takes place during student team meetings; so much of the learning is hidden from the instructor. Our long-term goal is to capture team interactions in order to develop a better understanding of collaborative learning in engineering design. This paper reports on a pilot study designed to understand the effects of electronic collaboration tools on the design process of student design teams. In the study, all teams were given the same design problem to solve, but some used pencil and paper, some used a regular whiteboard, and some used a shared digital whiteboard. While our study was a pilot study, it hints that the results of the design process are essentially the same whether students are co-located or distributed. However, we observed that students verbalized their arguments more when separated. The students in the distributed setting spent longer in each design step because they spent more time explaining ideas to students in the other room.**

Index Terms: Collaboration learning, Computer-mediated learning, Distributed environment, Student-centered learning

INTRODUCTION

Co-construction is the successful activity of knowledge building and problem solving between individuals [3]. Reflection and discussion promote critical thinking [4]. However, typical academic environments can undermine the learning goals of collaborative design projects. Scheduling and attending meetings are often difficult for students from different majors with different schedules and priorities and finding a physical space to work in is just as difficult. Brainstorming is a crucial process in design, and design students spend a lot of time brainstorming ideas on paper and whiteboards during their meetings. Because many social negotiations are involved – both verbal and non-verbal – brainstorming is usually done only in face to face meetings. In this study, we study the effect of electronic collaboration tools on the quality of brainstorming sessions in student design teams.

Many studies have examined how students collaborate and how students design, but few have examined how students collaborate and learn from each other while designing [1]. The design and development process for students in design teams requires that they build and retain knowledge through discussions, sharing artifacts, and creating documents. Team design also requires that students coordinate schedules, artifacts, documents, deadlines, and deliverables. Teams need to develop a shared language in order to communicate well. Students rarely have a dedicated design space to work in and store their documents in, so their meeting spaces need to be cleared at the end of a meeting, and each team member leaves a meeting with pieces of a puzzle that needs to be reconstructed at the beginning of the next meeting [1]. Students cannot attend every meeting of their teams, so they need tools and strategies to stay up-to-date on their project.

Our goal is to design tools that support the processes of knowledge co-construction and reflection that occurs during design projects. We are developing a suite of tools, called the Kiva, to support design students learning through collaboration. We are developing both online and physicals spaces for student teams to use as a digital equivalent to a dedicated design space. Students can store their documents and discuss their ideas online using the Kiva Web. In the physical Kiva, we have integrated digital whiteboard hardware and software that enables students to collaborate with each other without being co-located. Students must still be able to go through a similar design process in the physical Kiva as they would if they were using pencil and paper.

Before deploying this tool, we wanted to examine the electronic whiteboard technology to ensure that when the students use this technology for design, their design process is essentially the same with conventional paper or whiteboard. We developed an experiment to test student collaboration when their design team is co-located versus when it is not. We ran into many confounding variables during our analysis which we could not have predicted would be a problem ahead of time, and thus this paper describes our methodology and motivation for studying the problem of non-co-located design teams and make suggestions for improving our methodology.

BACKGROUND

I. Student-centered learning

Student-centered learning is characterized by problem-based activities and projects that promote students' active involvement in their learning process [2]. All students in a design class do not necessarily need to learn exactly the same factual material, but all students should gain a deeper understanding of a domain when they have finished their projects. A typical example of student-centered learning is a team project designed for students to gain domain knowledge through their own research and interaction with their teammates. Below are some differences between student involvements in student- versus teacher-centered learning styles.

TABLE 1
CHARACTERISTICS OF STUDENT-CENTERED LEARNING [2]

Student-centered	*Teacher-centered*
Students' experience as well as their knowledge is considered	Focuses primarily on increasing students' knowledge
Feedback is primarily concerned with helping students to improve	Feedback is primarily concerned with telling students whether they have fulfilled the assessment criteria
Active learning	Passive learning
Problem-based	Discipline-based
Emphasizes development of understanding and constructions of meaning	Emphasizes transmission of knowledge

Undergraduate design students are novices both in their domain knowledge and in their knowledge of the design process; therefore, in student-centered learning the instructor must facilitate the mastery of new domain knowledge as well as mastery of the team design process. The greatest learning occurs not when the teams divide the project into independent parts, solve them individually, and then put the results together into a final document, but rather when teams work together and build on each other's knowledge to create a product that no one of them could have created individually.

II. Collaborative Learning

Many studies have examined how students collaborate when they already know a subject, and many have examined how students learn known subjects from teachers and tutors, but few examine how students collaborate and learn from each other during design, particularly when the collaboration is computer-mediated [1]. Because our goal is to capture the team interactions during design, we are driven to use computer-based tools. In addition, our strategy is to leverage the tools the students already use and are comfortable with, including, laptops, cell phones, chat, etc. Many of the existing commercial and research tools for Computer Supported Learning (CSL) and Computer Supported Collaborative Learning (CSCL) are meant for subjects that have a common way of teaching them and a common way of analyzing a student's knowledge of a subject. Many of the studies examine how students learn a specific subject facilitated by a computer application. Our research on computer-mediated collaborative design focuses on how to use computer-based tools to support student design teams learning both the design process and the subject matter they encounter as their design progresses.

Considerable research has been conducted looking at collaborative teams in the workplace. Although student collaborative teams share many of the features as those in industry, there are important differences. As with industry design teams, student teams need to build and retain knowledge through discussions, artifacts, and documents as their design evolves. Both kinds of teams require coordination of schedules, deadlines and deliverables, and both need to develop a shared language in order to work collaboratively. However, for workplace teams the ultimate goal is the final product, while for student design teams the goal is to learn about the design process and to master new domain knowledge. Thus, for students what happens during the process is more important than the end product.

For these reasons, collaboration tools designed for industry rarely work well for student teams. In response, design faculty on many campuses have begun to work on collaboration tools for student teams, particularly for distributed teams [4, 5, 6, 7, 8, 9]. Computer-mediated support can provide mobility, flexibility, and the persistence of information to meet the demands of individual and collaborative work at, and between, meetings. But, because students are novices, tools designed for them must also support the development of process skills and knowledge. Hence, our focus is to develop tools that encourage process competence, constructive skills, and reflective practice.

III. Existing Coding Schemes

We are exploring computer-mediated collaborative design instead of CSCW or CSCL because we want to create an environment in which students can collaborate and learn from each other just as they would in a standard design environment. In order to study both the design process and the collaboration process, we combine existing coding schemes for each of these processes.

Atman et al. have performed many studies on how individual engineering students design. They have examined the differences between the design processes of seniors and freshmen [10]. Their coding scheme reflects ten distinct design activities that students move through while they work on a design problem: identification of need, problem definition, gathering of information, generating ideas, modeling, feasibility analysis, evaluation, decision, communication, and implementation. We used these design steps to divide our design task into distinct parts and to analyze each activity individually for how teams speak to and interact with each other.

Soller and Lesgold analyzed how teams learn from each other through active learning [11]. They broke their coding scheme into three aspects of team learning: active learning, conversation, and creative conflict. In active learning, students inform, motivate, and request information and ideas from each other; in conversation, they included task maintenance and acknowledgement; and in creative conflict, students can argue or be mediators. In student-centered learning, all three aspects are needed or teams become dysfunctional and students do not learn from each other. We used this basic model to code the team interactions in our experiment, focusing on active learning. By examining the learning activities in terms of Atman's design steps, we can examine the differences in collaborative learning between collocated and non-collocated teams of students.

IV. The Kiva

Through an iterative, user-centered design process, we are designing and building tools to support students learning through collaboration, co-construction, and reflection. We have been conducting empirical studies to evaluate their usability and their contribution to learning. The environment is called the Kiva, a gathering place. The Kiva Web is a web application designed to extend students' ability to share information and to learn from each other. Members contribute to the content, centralizing the discussion that surrounds the various artifacts and documents [12].

The Kiva embodies our vision for an interactive physical and digital workspace that addresses the requirements of interdisciplinary teams. It is the digital equivalent of a dedicated project room. Teams share non-dedicated physical spaces and restore their team's project work at the flip of a switch. Walls become interactive surfaces that display work in progress. The rooms are outfitted with an interactive whiteboard, called eBeam, designed to support team brainstorming and continuity of work between team sessions. Teams can use it to generate and organize information to build shared arguments. Content, in the form of electronic artifacts, originates from three sources: files or images loaded to the surface, annotations and drawings on the surface itself, and the web. Users can interact during or between meetings. They can save and restore their workspace using the whiteboard software, and they can meet in any classroom with a projector [13]. When students work in separate places, they can network their whiteboards to see what their teammates are writing on the board in real time; they can also speak to each other via telecongerencing .

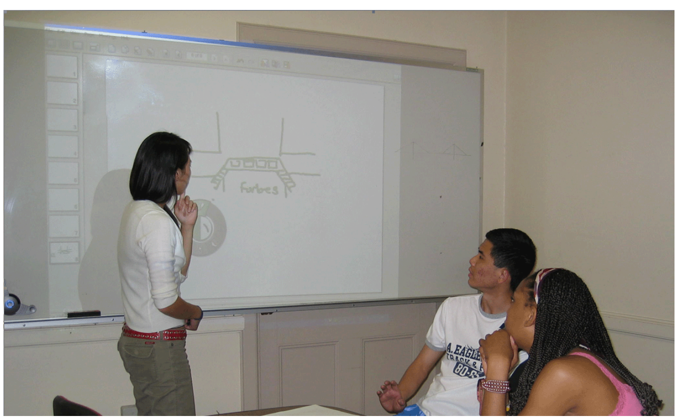


FIGURE 1
STUDENTS USING A KIVA

V. eBeam Interactive

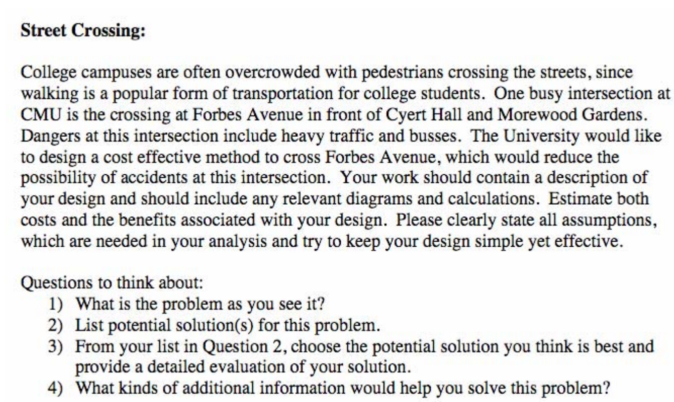
eBeam Interactive is a commercial digital whiteboard product we use in the Kiva, which gives users the ability to interact with a projected computer desktop using a digital device which acts like a mouse and a pen on the whiteboard. The software allows users to write virtually on the projected image as well as draw shapes and use lines and arrows. Users can use the mouse option to open and use other applications. Users can also share or network their meetings with other people to interact on online through the whiteboard. The topic of our study is the effect on the design process when students in different locations can collaborate on a shared, networked digital whiteboard.

METHOD

I. Experimental Procedure

The task that we gave teams of students to complete was first designed by Atman and was originally performed with individual designers instead of design teams [10]. We used this task because it had been used in several studies, so it was already refined and the findings had been replicated. In the experiment, teams of 3-4 students were given the task of designing a new way for students to cross a busy road near Carnegie Mellon because of the number of pedestrian accidents. We added questions to the end of the task for the students to answer, which helped them in the design process and also served as a division between parts of the task. The students were given 30 minutes to complete the task, but were free to leave before 30 minutes was up when they thought they solved the problem; however, they were required to complete all of the parts of the task before leaving.

Out of the 10 design steps that Atman outlines, we expected students to (in abbreviated form) define the problem, share information and generate ideas (brainstorming), analyze and evaluate their options, and make a decision as to which one is best. They were required to include a cost analysis of their plan, which factored into their feasibility analysis but was a separate step in our study.



Street Crossing:

College campuses are often overcrowded with pedestrians crossing the streets, since walking is a popular form of transportation for college students. One busy intersection at CMU is the crossing at Forbes Avenue in front of Cyert Hall and Morewood Gardens. Dangers at this intersection include heavy traffic and busses. The University would like to design a cost effective method to cross Forbes Avenue, which would reduce the possibility of accidents at this intersection. Your work should contain a description of your design and should include any relevant diagrams and calculations. Estimate both costs and the benefits associated with your design. Please clearly state all assumptions, which are needed in your analysis and try to keep your design simple yet effective.

Questions to think about:
1) What is the problem as you see it?
2) List potential solution(s) for this problem.
3) From your list in Question 2, choose the potential solution you think is best and provide a detailed evaluation of your solution.
4) What kinds of additional information would help you solve this problem?

FIGURE 2
PRESENTED TASK [10]

II. Experimental Design

The purpose of the study was to measure differences between how students in teams that are co-located interact versus those that are not. We were interested in differences in brainstorming ideas, arguing about ideas, and managing time. We hypothesized that there would be differences between the co-located versus non-co-located condition in how vocal the teams would be during their brainstorming and how vocal their task management would be, but that those differences would not affect the overall completion of the task.

EXPERIMENT

I. Subjects

We recruited students from an online Carnegie Mellon newsgroup and paid them $10 for the experiment. Teams were randomly assigned to one of three conditions for solving the problem - pencil and paper design with a collocated team, digital shared space in one room, and digital shared space plus teleconferencing in separate rooms. Students were assigned to teams based on their availability and when they volunteered. In total, 7 teams did the experiment: one with pencil and paper, three with the digital whiteboard in one room, and three with the digital whiteboard in two rooms.

II. Experimental Manipulation

The independent variable that we manipulated was whether all of the members of the team were in the same room or split between two rooms. In the co-located condition, the students were either given pencil, paper, and a regular whiteboard to use or were given the digital whiteboard, with some instruction. The pencil and paper team was used as a control to ensure that there was no difference just in using the digital whiteboard instead of paper when the team was co-located. In the two-room condition, the eBeam digital whiteboards in two Kivas were networked together, and the team communicated through teleconferencing and their drawings on the board. The dependent variable we were measuring was the number of each type of utterance per idea per person spoken by the members of the team during the period of time the team was brainstorming ideas, refining them, and then selecting one.

III. Analysis Techniques

The teams were videotaped, and all their artifacts were saved, including the virtual whiteboard spaces. Transcriptions of the videotapes were coded by the person speaking and by idea the person was talking about. We wanted to examine how the team members were talking about the ideas to look for particular patterns between the two conditions.

We created graphs of the people in the teams and the ideas they generated in the brainstorming and decision-making parts of the task. The graphs illustrated how different team members spoke about different ideas and who was talking about them based on the graphs. We graphed the brainstorming linearly and between team members to better examine interaction. Distributed teams generated more ideas and had more communication about the ideas than those in the same room.

After further analyzing the transcripts, we found that most of the teams' time was spent brainstorming and narrowing their alternatives. The majority of the learning outlined by Soller and Lesgold happens in these steps because this is when most of the ideas are generated and debated and when students share their knowledge about the topics, so it was ideal to analyze these aspects of the task [11]. Also, for all of the teams, these two sections had a distinct start and end. Although the brainstorming and analysis were combined in some teams, there was always a definitive decision to move on to cost analysis.

We observed several different techniques for how the teams generated ideas. Some teams brainstormed individually and then enumerated their ideas. Other teams discussed one idea at a time and then moved on to another and compared their ideas as they discussed. Table 4 shows that generation of, responses to, counterarguments to, and information about ideas are often interleaved. We identified parts of brainstorming that were present and noticed they were similar to Soller and Lesgold's parts of active learning [11].

TABLE 2
EXAMPLE OF A TEAM GENERATING AND DEBATING IDEAS SIMULTANEOUSLY

ok, so you have like 30 people waiting to cross the street all at once
yeah, I've seen that before…
so, I don't know maybe we can do something to alleviate that
but the only way I see to do that would be to shorten the length of the red lights so it would be
yeah yeah
so I don't think people would be too happy with that
yeah yeah
what about
lets build a bridge
yeah that was what was on my mind too
yeah
they do that in other countries and it works
well they have a bridge down on pitts campus, I'm pretty sure it goes between buildings

We chose to use Soller and Lesgold's the coding scheme because we wanted to focus on the aspects of their active learning and creative conflict – information (inform and request), argumentation (motivate, argue, and mediate), but we did not focus on the overarching themes [11]. Task management (task maintenance) was used to examine when and how often students switched explicitly between different parts of the task. Team organization was added to the coding scheme even though it was not present in Soller and Lesgold because sometimes teams chose to split up the work based on location or team member strengths.

Each utterance by a student was classified into one of four types based off the Soller and Lesgold ideas: 1) Argumentation for proposing/motivating ideas, disagreeing and agreeing, etc.; 2) Information for giving facts or information; 3) Task Management for what part of the task the team is focusing on; and 4) Team Organization for who is working on what. Argumentation and Information are both forms of elaborating ideas, whereas Task Management and Team Organization are both types of management. When students discuss ideas, they either argue something about them or give information about them. When a team member is ready to move on to another part of the task or when a student suggests how the team should complete a part of the task, they discuss task management or team organization.

We can use these four codes to analyze how students interact with each other and collaborate to solve the design problem. We would expect that with fewer non-verbal cues for the teams that are separated, they should have more total utterances and more arguments because they have to speak their opinions explicitly instead of assuming that the other team members can read their body language. Also, we would expect more team management utterances for these teams, because students must negotiate explicitly to move on to a different part of the task.

TABLE 3
TYPES OF UTTERANCES

Type of Utterance	Example
Argument	"I think that the crosswalk is a good idea", "so I don't think people would be too happy with that"
Information	"Wood is cheaper than like anything else", "well they have a bridge down on Pitt's campus, I'm pretty sure it goes between buildings"
Task Management	"Do you have any other ideas?"
Team Organization	"Does one of us want to write up an evaluation?", "I have an idea, we'll all figure out what the possibilities are and then share them in the team"

RESULTS

Each team generated at least three ideas, which were similar across all groups: building a bridge for the students to cross, digging a tunnel for the students to use, and changing the timings of the lights on the street. Each team spent between 10 and 20 minutes brainstorming and deciding on which idea to implement. Their decisions do not seem to be correlated with how much time they spent brainstorming the idea nor in which idea was generated first.

Each team member contributed different ideas and opinions, so our analysis focuses on how each person in each team contributed with each type of utterance for each idea that was proposed using the analysis method described above. There were statistical differences in the total number of arguments and task management utterances made between conditions – 63.33 and 4.3 utterances for co-located teams versus 127.5 and 14 for non-co-located teams. One might argue that the total number of utterances was greater just because the teams in separate rooms spent more time brainstorming than the teams who were co-located. While these teams did spend more time brainstorming, we normalized by the total number of utterances in the team. The percentage of elaboration and management are both statistically different – 94% and 6% for co-located on average versus 91.7% and 8.3% for non-co-located teams. However, the amount of information team members offered on average about their ideas was not statistically different –20.9% of all utterances for co-located teams versus 19.3% for non-co-located teams. This supports the assertion that the students who were assigned to the two-room condition did not have greater prior knowledge about the subject than other teams. Table 4 summarizes the utterances by condition and category.

TABLE 4
UTTERANCE BREAKDOWN BY CONDITION AND CATEGORY

	co-located	non co-located
# number of argumentative utterances	63.3	127.5
# of task management utterances	4.3	14

Students in the non co-located teams spent more time task managing than teams that were in one room. This can be attributed to not having the non-verbal cues to indicate that the other teammates are done with a specific subject and want to move on. When a team member in a non-co-located team wants to move on, that person must negotiate socially to convince the rest of the team to move to another topic; this proved difficult for some of the teams that were in separate rooms. For example, Table 5 gives the utterances of one of the participants in a non co-located team who could not get teammates to acknowledge the approaching deadline. One might attribute this phenomenon to the fact that students may not have an understanding of how their team members show that they are bored or tired, either due to the members' social skills or to the short amount of time spent in the task. Another study that controls for the team make-up and controls for the team communication would be needed to resolve this issue.

TABLE 5
EXAMPLE OF NEGOTIATION TO ATTEMPT TO FINISH THE TASK AFTER THE 6 MINUTE WARNING

I don't think we have a lot of time left so lets try to be efficient
ok I don't think we have that much time
how much time do we have left
ok how much time do we have left

On the other hand, an analysis of team data by ideas reveals no significant differences between conditions. In this pilot study, the condition did not affect how the teams brainstormed ideas through argumentation and sharing.

SUMMARY

This pilot study suggests that there is no difference in how student teams brainstorm and refine their ideas when they are co-located versus separate. We also see that students verbalize their arguments more when they are separated. In addition, instead of assuming that everyone understands them, students in non co-located teams explain their ideas more fully, ask more questions, and clarify their ideas more completely, which can lead to greater learning.

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REFERENCES

[1] Finger, S, Gelman, D., Fay, A., Szczerban, M., "A Design Collaboratory for Engineering Students," International Conference on Engineering Design, Melbourne Australia, August 2005.

[2] Brown, G. How Students Learn. Supplement to RoutledgeFalmer Key Guides for Effective Teaching in Higher Education, London: RoutledgeFalmer, http://www.routledgefalmer.com/series/kgethe/resource.pdf, 2004.

[3] Li, J., Exploring collaborative discovery, PhD thesis, Psychology, Carnegie Mellon University, 2003.

[4] Miyake N., Shirouzu, H., "Understanding and Scaffolding Constructive Collaboration," Proceedings of the Twenty-Fourth Annual Conference of the Cognitive Science Society, 48, 2002.

[5] Ion, W.J., Thomson, A.I., Mailer, D.J., "Development and evaluation of a virtual design studio," *Proceedings of EDE '99,* University of Strathclyde, September 1999, pp. 163-172.

[6] Subrahmanian, E., Westerberg, A., Talukdar, S., Garrett, J., Jacobson, A., Paredis, C., Amon, C., "Integrating Social Aspects and Group Work Aspects in Engineering Design Education," *Mudd Design Workshop III*, May 2001.

[7] Milne, A., Winograd, T., "The iLoft Project: A Technologically Advanced Collaborative Design Workspace as Re-search Instrument," *Proceedings of the ICED'03*, Stockholm, Sweden, 2003.

[8] Lahti, H., Seitamaa-Hakkarainen, P., Hakkarainen, K., "Collaboration patterns in computer-supported collaborative designing," *Design Studies*. Vol 25, No. 4, 2004, pp. 351–371.

[9] Kirschman, J.S., Greenstein, J.S., "The use of groupware for collaboration in distributed student engineering design teams," *Journal of Engineering Education*, 2002, pp. 403-407.

[10] Atman, C., Turns, J., "Studying Engineering Design Learning: A Case Study in the Application of Protocol Analysis and the Development of Measures," Knowing and learning to design: Cognitive perspectives in design education, C. Eastman, M. McCracken, and W. Newsletter (Eds.), Elsevier: New York, 2005, pp. 37-62.

[11] Soller, A., Lesgold, A. "Analyzing Peer Dialogue from an Active Learning Perspective," Proceedings of the AI-ED 99 Workshop: Analysing Educational Dialogue Interaction: Towards Models that Support Learning, 1999.

[12] Finger, S, Gelman, D., Fay, A., Szczerban, M., "Supporting Collaborative Learning in Engineering Design," International Journal of Expert Systems and Applications, to appear.

[13] Finger, S, Gelman, D., Fay, A., Szczerban, M., "Assessing Collaborative Learning in Engineering Design," International Journal of Engineering Education,v22, no 3, 2006, in press..