Computer-Supported Collaborative Design: A Case Study of Distributed Engineering Design Teams

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Abstract - Preparing students to succeed in a global economy is a challenge now facing higher education institutions. Engineering students must not only have the ability to apply technical knowledge, but also the abilities to communicate effectively, to function on multi-disciplinary teams and to use the modern engineering tools necessary for engineering practice. Among such tools, computer-mediated communication (CMC) tools can facilitate collaborative projects undertaken by teams of engineers distributed across the globe. This study investigates the intrinsic and complex aspects of computer-supported collaborative engineering design. Twenty four international and American, under-graduate and graduate, students enrolled in engineering related programs participated in a two-week project on the conceptual design of a green roof to be built on the Carnegie Mellon campus. The participants were distributed in eight triads; all teams worked on the same design task. They had no face-to-face interactions and used only a suite of CMC tools to collaborate. The tools supported both synchronous and asynchronous communication. The participants’ academic, cultural, and personality profiles were assessed using standardized questionnaires. Participants filled out a pre-survey on their prior experiences in teamwork, their English proficiency in reading, writing and speaking, use of CMC tools, and their prior knowledge about the design task. All design interactions were captured in digital form. At the end of the experiment, a post-test and survey were administered and a subset of students interviewed. The study investigates correlations among student characteristics, interaction patterns, and learning achievement in this computer-supported collaborative environment.

Index Terms – Computer-supported collaborative learning, Computer-mediated communication, Engineering Design Education.

INTRODUCTION

Large engineering projects are often complex and involve many professionals with different expertise and experiences working together throughout all project phases. These projects are essentially collaborative in nature, i.e., teamwork is the primary work mode. In addition to traditional technical skills, companies now expect engineering graduates to demonstrate additional skills [1]. Among the most important of these new skills is the ability to communicate clearly and to work effectively as members of teams.

According to the 2005-06 Accreditation Board for Engineering and Technology (ABET) criteria for accrediting engineering programs [2], engineering students should acquire not only an ability to apply technical knowledge, but also an ability to communicate effectively and to function on multi-disciplinary teams. Furthermore, they should be able to use techniques, skills and modern engineering tools necessary for engineering practice.

Collaborative learning is an effective instructional technique that is known to promote the retention of declarative knowledge, application of procedural knowledge to new situations, acquisition of contextual knowledge, and development of higher-order cognitive skills [3]. Furthermore, research on collaborative learning has provided evidence that it is more effective than competitive and individualistic learning in promoting academic, social, psychological, and attitudinal student outcomes, leading to a higher quality of the academic experience [4]. The success of collaborative learning, confirmed at the pre-collegiate level, has encouraged faculty to explore its use in higher education.

Recent advances of information technology are making computer-mediated communication (CMC) and collaboration tools more accessible and affordable. The combination of collaborative learning and information technology, known as computer-supported collaborative learning (CSCL), is a promising new form of instruction and learning [5]. CMC tools can perform a unique role as facilitating agents to support collaborative projects undertaken by teams of engineers distributed across the globe.

The recent promotion of CSCL is based on the extensive body of evidence of the effectiveness of face-to-face collaborative learning. The conditions under which face-to-face collaborative learning is known to be effective and the already identified common interaction patterns and behaviors of individuals working collaboratively face-to-face are usually taken for granted in computer-supported collaborative learning environments. However, studies investigating patterns of interaction and group dynamics of individuals working online have reported some unpredictable group behaviors [6]. These findings raise important issues about the use of computer-mediated communication and collaboration tools in educational settings.

Researchers have investigated potential critical factors that may affect group performance when using CMC tools.

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San Juan, PR

9th International Conference on Engineering Education

July 23 – 28, 2006

R4D-12
including group characteristics, task characteristics, technology characteristics, and student characteristics [7]-[9]. A few studies have investigated how students’ characteristics are associated with the individual use of technology. Only two have investigated how student characteristics affect group performance [10]-[11].

Through an interpretative, qualitative case study, we investigate how student diversity influences the effectiveness of CSCL. We evaluate the effect of individual students’ characteristics, working in multi-cultural, multi-disciplinary engineering teams, on their collaboration patterns. Diversity is assessed by measures such as nationality, academic level, personality type, learning styles, multiple intelligences, and prior experiences with teamwork and technology. Our primary goal is to determine whether any cohort of students is potentially at risk of academic and professional failure within a collaborative learning and work setting that relies primarily on computer-mediated communication tools.

Our approach to evaluating the effectiveness of CSCL uses a two-step investigation model: first, a correlation analysis investigates the relationship between individual and group characteristics and the electronic interaction patterns; and second, a correlation analysis investigates the relationship between electronic interactions patterns identified in the first step and student academic outcomes. Figure 1 illustrates this model.

**Methodology**

**I. Case Study**

This case study was designed to investigate the effect of student and group characteristics on the use of CMC tools by engineering design teams. This month long case study was performed over the summer, was completely independent from any course work, and the students were dispersed across the U.S. for summer jobs.

**II. Subjects**

Twenty-four U.S. and international students enrolled in engineering-related programs from either Carnegie Mellon or the University of Pittsburgh participated in this case-study. Subjects’ average age was 23 years old. Eleven participants were undergraduate students and thirteen were graduate students at either the master or doctoral level. Eleven were female and thirteen were male. The students were from the U.S., Canada, Brazil, Chile, India, China, and Taiwan. Their fields of study were: Biomedical and Health Engineering, Chemical Engineering, Civil Engineering, Electrical Engineering, Computer Engineering, Computer Science, Engineering and Public Policy, Environmental Engineering, Mechanical Engineering, and Physics. Four of the students were working on joint degrees between two of the fields listed (e.g., Civil Engineering/Engineering and Public Policy and Chemical Engineering/Biomedical and Health Engineering). Participants were required to have Internet access over the summer.

**III. Groups**

Subjects were divided into eight groups of three, balanced by their majors and backgrounds. The main criterion for forming groups was to create a mix of disciplinary expertise, regardless the participants’ age, gender, nationality, and/or institution.

**IV. Computer-Mediated Communication Tools**

Participants used a suite of CMC tools to support their collaboration including asynchronous communication systems (email, discussion board, and file exchange systems) and synchronous communication systems (chat and shared whiteboard). All tools, except for electronic mail, were available through Version 5 of Blackboard [12], an online course management system used widely at Carnegie Mellon to support courses on and off campus. After logging in to Blackboard, students could access content areas including: announcements, course information, staff information, course documents, communication tools, and external links. Each group had a page, which gave them access to their tools for intra-group communication: discussion board, chat, and a digital drop box for file exchanges. Participants used their personal e-mail accounts and were required to use a mail alias whenever sending messages to their team members.

**V. Design Task**

For the study, the participants were given the design task of developing detailed plans for a green roof on the Carnegie Mellon campus. A green roof is a roof that is covered in vegetation in order to reduce storm water runoff as well as reduce heating and cooling costs. Facilities Management Services (FMS) at Carnegie Mellon had already determined the site for the green roof and had done some preliminary analyses, including a structural analysis. FMS wanted a green roof that would reduce storm water runoff by 15-90%; reduce heating and cooling energy consumption by 20-30%; promote diverse vegetation by more effective use of rain water; and encourage student activities involving the green roof to increase awareness of and involvement in environmental education and research. They also wanted a system that would enable them to measure the benefits of installing the green roof.

The teams were given background information on green roofs, Pittsburgh weather, the Pittsburgh storm water overflow problem, appropriate vegetation for green roofs, the Americans with Disabilities Act (ADA), CAD floor plans, and the
structural report for the selected building. The participants were given electronic access to consultants who could answer questions about, e.g., campus utilities and green practices at Carnegie Mellon.

Two weeks from the start of the experiment, each team had to make a 15 minute presentation of their design for the green roof to a panel of judges composed of representatives from FMS and the campus community. The panel selected the best design based on the following criteria: 1) The design includes systems that will enable FMS to measure the benefits of the green roof; 2) The design meets safety and ADA requirements; 3) The design minimizes maintenance requirement; and 4) The overall design meets the goal of encouraging student activities involving the green roof.

Participants received an hourly stipend for attending meetings and working on the design task. They received a bonus of $100.00 for completing the experiment and were paid to participate in the post-experiment interviews. The winning team received an prize of $100.00 per member.

VI. Procedures

The participants were recruited using campus newsgroups. Participants were required to have an engineering or engineering-related degree and to have access to the internet over the summer. An introductory meeting was held on campus before the experiment started so the teams could meet each other and so we could provide them with detailed instructions, explain the experiment requirements, and the design task. One of the primary rules of the experiment was that all communications among the team members had to be done using computer-based communication.

During this initial meeting, the participants took a battery of tests to assess their individual characteristics. They also took a test on green roofs, storm water systems, and other knowledge relevant to the design task. A second pre-experiment meeting was held to provide the participants with training on the Blackboard tools. During this session, the participants set up their email alias lists and reviewed the rules for the experiment.

The participants were given two weeks to complete the design task. During the experiment, we monitored and captured the electronic interactions of each team. We are confident that the participants followed the experiment requirements, because in coding the data we found no instances that indicated topics were being discussed off-line. The primary reason for this high level of compliance is that most of the participants were off-campus for the summer and so the opportunity for face to face meetings was small.

Participants were required to upload the final presentation to Blackboard by the deadline and could not change anything between the deadline and the final presentation to the panel. Each team presented their design to the panel, and then panel selected the best design.

After the experiment, the participants retook the knowledge test. An outside expert interviewed a subset of the participants on their experiences during the design task.

I. Subjects’ Profiles

The following tests were administered to all participants.

- **Myers Briggs Type Indicator (MBTI):** This instrument assesses an individual’s personality type based on Jung’s theory on psychological type. The personality types have four dimensions: Extroversion or Introversion, Sensing or Intuition, Thinking or Feeling, and Judging or Perceiving. The psychological type is defined by a combination of four preferences [13].

- **Learning Styles Questionnaire (LSQ):** This instrument assesses the individual’s learning style based on Kolb’s experiential learning theory [14]. Four different styles are identified through this questionnaire: Activist, Reflector, Theorist, and Pragmatist [15].

- **Multiple Intelligence Developmental Assessment Scales (MIDAS):** This instrument assesses the individual’s multiple intelligences based on Gardner’s multiple intelligences theory [16]. This theory proposes that an individual possesses at least eight distinct forms of intelligences: Musical, Kinesthetic, Logical-Mathematical, Spatial, Linguistic, Interpersonal, Intrapersonal, and Naturalist [17].

We also developed a questionnaire to assess other individual characteristics of the participants. This questions were clustered into five sections: 1) personal data (age, gender, nationality, educational level); 2) data on English proficiency on reading, writing, and speaking; 3) assessing prior work experiences; 4), assessing prior team-work experience; and 5) information on prior use of computer-mediated communication tools (mode of communication, frequency of use, and perceived effectiveness).

II. Electronic Interactions

To ensure the capture of all the students’ electronic interactions, the experimenter participated in each team as a virtual member; she did not perform any design-related tasks. The experimenter’s participation was restricted to the role of an observer and receiver of all electronic interactions exchanged during the design project. The following capturing procedures were used for each type of tool:

- **Electronic mail:** Participants used a mail alias for their team. The experimenter was a virtual member in each team, so her e-mail address was included in each team’s mail alias. This procedure guaranteed that the experimenter captured all e-mails exchanged among students which were related to the experiment. No private mails were captured through this method.

- **Team discussion messages:** All posted messages in a discussion board are available to all team members. Only the participants in the team had access to the messages posted in the team’s discussion board. Since the experimenter was a virtual member in all teams, she had access to all messages as well.

- **Chat interactions:** All messages exchanged in chat rooms are available to all members participating in the chat. The
students used the virtual classroom (chat) tool in Blackboard. Blackboard automatically archives the log files of all teams’ chat interactions and all team members have access to the archives.

- **File attachments to e-mail and discussion boards:** These files were captured whenever an electronic mail message was exchanged or a team discussion message was posted to the discussion board.

- **File uploaded to the file exchange area:** Files posted to the team’s digital dropbox in Blackboard are available to all members. As a virtual member, the experimenter had access to the team’s private workspace and to all files uploaded to the file exchange area. All electronic interactions were clustered into eight datasets, one for each team, organized by mode of communication and by member in each team. The entire dataset composes the electronic interaction data that were used to investigate the correlation with participants’ individual characteristics, the electronic interaction data using the segmentation procedure described in Strijbos et al. [18]. Their procedure defines a “meaningful sentence” as the unit of analysis. A meaningful sentence is “a sentence or part of a compound sentence that can be regarded as ‘meaningful in itself regardless of the meaning of the coding categories.’” The meaningful segments in this study are the participants’ contributions to the entire team collaboration while performing the design task. For each participant, we calculated the total number of contributions for each mode of communication. We found no significant statistical correlation between any student’s individual characteristic with participation measured in terms of the total number of contributions.

Next, we performed a macro-analysis of the electronic communication based on the number of contributions from each member in a team to specific threads. Similar discussion topics were identified among the teams. Threads related to the design task requirements (e.g., roof layout, usage, vegetation, access, safety, benefits’ measurements, and maintenance) were grouped as a broader designing thread. Teams that used the chat tool for their virtual meetings had a general meeting thread, which encompasses threads for scheduling, initializing, and finalizing those meetings. The presentation thread includes threads for preparing the presentation slides, scheduling the presentation session and planning the presentation itself. All teams had an organizing thread, which consists of contributions related to organizing the team and their work. Other threads common threads included greetings, sharing resources, consulting experts, consulting experimenter, computational issues, etc.

From this macro-analysis, we observed different communication patterns within the teams and identified their level of collaboration. Figure 2 illustrates the patterns for two teams that used different approaches to accomplish the design task. Team 2 is representative of a collaborative team. Members of a collaborative team discuss each portion of the problem, contribute ideas, argue and review their opinions until a consensus is reached and the problem is solved. One of the most important characteristics of collaborative teams is the “interdependence of the group members as they share ideas and reach a conclusion” [19]. Team 5 is a representative of a cooperative team. Members in a cooperative team divide the work so that each member solves a portion of the problem, and then they put the parts together; that is, they use a divide and conquer approach.

**Future Work**

The next step in our investigation will be a micro-analysis of the interactions based on the content analysis of the participants’ contributions. The contributions will be categorized based on two different coding schemes describing the design process phases and the collaboration process. Using the total number of contributions in each category from each coding scheme as a more refined measure of participation, we...
ACKNOWLEDGMENT

This study is financially supported by the Brazilian National Council for Scientific and Technological Development (CNPq) and by the Vice Provost for Education’s Office, the Graduate Student Assembly, and FMS - all from Carnegie Mellon. We would like to acknowledge the support of the National Science Foundation grant EEC-0203448. We would also like to thank our colleagues Susan Ambrose, Anne Faye, and Indira Nair.

REFERENCES


Figure 2
COLLABORATIVE VS COOPERATIVE TEAMS THREAD ANALYSIS


