The Effects of Computing Technology for Design Collaboration in Face-To-Face and Distributed Settings

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Abstract: This paper presents two studies of four pairs of design students collaborating during two design sessions in both face-to-face and distributed settings while using computer-mediated communication (CMC) technologies and a collaborative virtual environment (CVE). The design session were analyzed through systematic observations, which focused on how much time the students worked "together" and "individually" in the design process. The results indicated that teams spent more time working together when using programs that support shared sketching abilities or shared viewing of 3D objects. This finding suggests that the CVE can be a more useful tool if it provides better sharing capabilities, such as the capability to manipulate 3D modeling in CVE in real time.

Key words: Collaborative design, computer-supported collaborative design, CMC; computer-mediated communication, CVE; collaborative virtual environment

1. Introduction

Individuals working on design teams are increasingly geographically distributed. That is, they work in different locations. As more design teams have members that are geographically-distributed, a greater need for technology has arisen [11]. Technology enables communication and information sharing between distributed team members [22]. Computer-mediated communication (CMC) technologies such as email or Instant Messenger support collaboration by facilitating communication, especially long-distance communication [18]. Other types of technology can be used to exchange files. For example, designers can propose ideas on the development of a design, exchange archived information, and present ideas to others (e.g., clients) [4, 6]. Other computer-based tools that could help distributed designers collaborate are collaborative virtual environments (CVEs). CVEs are online digital places and spaces where people can play and work together [2]. CVEs support group activities by enabling multiple users to meet as graphical embodiments called “avatars” and by allowing users to see and experience the same virtual objects and virtual places [1].

Despite advancements in modern technology, numerous studies have demonstrated that the most effective form of communication is face-to-face [10, 16, 23, 24]. Thus, we are interested in whether existing CMC and CVEs can make distributed collaboration as effective as group work in a face-to-face setting. This research investigated how distributed design teams create and share design information using technologies and how communication activities performed by design teams in face-to-face and distributed settings differ.
Many studies have shown that groups produce better results than individual [7, 9, 12, 17, 25], as the design process is something that inherently cannot be done by an individual alone [13-15]. Whether design projects are successful may depend on how team members share and support each others’ ideas. Therefore, collaborative activities comprise an integral part of teamwork [13, 14]. Although a number of studies have examined the role of computer supported communication in distributed teams (e.g., education, training) [3, 19-21], little research has focused on the role of computer-supported systems in promoting effective collaboration among designers in a distributed environment.

The main purpose of this research was to develop recommendations for a system that would more effectively support design communication, the interaction of designers, and the sharing of design in formation. Therefore, this study examined design teams, with the focus on general issues of collaboration in design teams and the types of technologies used in such collaboration. In particular, we focused on whether CMC technologies and CVE could facilitate design collaboration in distributed settings, and if so, which types are most effective.

2. Study 1

The first study was used to investigate how designers in face-to-face (F2F) and distributed (DIS) settings collaborate through CMC and CVE. CMC included technologies such as email or Instant Messenger, and CVEs included technologies such as virtual reality and computer-aided design (CAD) software. Design team’s activities in the two different settings were compared.

2.1 Experimental Design

Two design teams collaborated on two different creative design tasks in both F2F and DIS settings: 1) a pill box for a woman with mild memory loss and 2) an extension cord for a man with only one functioning hand. For Task 1, design team A was in the DIS setting and design team B was in the F2F setting. For Task 2, the settings were reversed.

Participants

Participants included pairs of design students from the industrial design and architecture programs in the College of Architecture at Georgia Institute of Technology. All participants were male, three of whom were graduate students and one a 3rd year undergraduate student. All participants were familiar with the CMC technologies and CAD software used in the experiment, and they indicated they had experience using virtual shared 3D environments such as Second Life, VRML, and Kaneva.

Experimental Setup

The experiment took place in a usability lab equipped with four Internet Protocol (IP) cameras; two capturing a bird’s eye video of the participants and two focused on the screen of each participant. In the F2F setting, participants were seated next to each other and they were able to talk and see one another, as illustrated in Figure 1. In the DIS setting, participants were located in the same room but with a panel separating them. They were not able to see or talk to each other except via the CMC and the CVE technologies, as illustrated in Figure 2.
Communication and Design Tools

During a session, each designer was provided with a laptop with the Windows XP professional operating system and software available for the design tasks. Table 1 shows the tools provided to the designers. The CMC technologies included email, Skype, and Instant Messenger. The CVE was ARCH8803, a program built on top of the UnrealEngine2 Runtime 2226.20.02 and developed by the IMAGINE Lab at the Georgia Institute of Technology. Participants were also provided with traditional design tools such as pen and paper, and digital communication tools such as a webcam and a headset. Both teams were also given a 3ds Max file with a model of an existing pill box or an extension cord. The models were also placed in the Unreal virtual environment, as illustrated in Figures 3 and 4.

<table>
<thead>
<tr>
<th>Table 1. Experimental Design of Study 1</th>
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<tbody>
<tr>
<td><strong>Task 1 (1 hour): Pill box</strong></td>
</tr>
<tr>
<td>Team A (DIS)</td>
</tr>
<tr>
<td>Team B (F2F)</td>
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</tbody>
</table>

**Provided Tools**

* Required to use Unreal in both F2F and DIS settings

<table>
<thead>
<tr>
<th>CMC</th>
<th>Email</th>
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<tbody>
<tr>
<td></td>
<td>Skype</td>
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<td></td>
<td>Instant Messenger (IM)</td>
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<table>
<thead>
<tr>
<th>CAD</th>
<th>Autodesk® 3ds Max® 2009 32-bit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid Works 2008</td>
</tr>
<tr>
<td></td>
<td>Adobe Illustrator CS / CS2</td>
</tr>
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<td></td>
<td>Adobe Photoshop CS / CS2</td>
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</tbody>
</table>

| CVE          | UnrealEngine2 Runtime 2226.20.02 (Unreal) |

<table>
<thead>
<tr>
<th>Others</th>
<th>Pen and paper</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Webcam and headset</td>
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</table>
Procedure
Design students were randomly assigned to teams, each team was given one hour to redesign one small product. Both teams worked on the pill box redesign problem during the first session and the extension cord redesign problem during the second session. The design teams had one hour to complete each task, during which time they were required to use the CVE (Unreal) for both two tasks; however, they could choose any other tools to use. By the end of the hour, the teams submitted a 16”x16” poster (pdf format) of their final design. At the conclusion of the second design session, participants responded to questions about the setting in which they preferred to work with their teammate and in which setting they felt more engaged in the design process.

Video and Data Coding
The stream of data from each workshop was segmented, coded, and analyzed using Observer XT 8.0 software. Observations focused on design activities, the use of communication tools, and the working modes of the team members, either together or individually. The information gathered from the observations was used to determine the impact of the design tools on the collaborative design process. Of primary interest was the technology used when the teammates worked together.

2.2 Results of Study 1
Both teams in both settings exhibited a similar pattern in collaboration strategy. First, the teammates worked together briefly to arrive at a design concept. They then divided the work so that each person could work independently (3D modeling task or 2D graphic task) to produce the final design. Designers used verbal communication (i.e., talking) most often to share their ideas. Both teams in the DIS setting used Skype which allowed them to talk to and see each other by video call. They used Unreal less than 10% of the total time to see, move around, and observe the existing products within the Unreal virtual environment. Both teams used webcams for sharing their 2D/3D graphic models by pointing at the screen, as shown in Figure 5.

![Figure 5 Sharing 2D/3D graphic using a webcam](image)

![Figure 6 Working modes (together/individual)](image)

Figure 6 shows the percentage of time each team in each setting worked together and individually. In the F2F setting, Team A worked together about 63% of the time and individually about 37% of the time. However, Team A worked together about 33% more in the DIS setting than in the F2F setting. Thus, in the second workshop, Team A was able to come up with a design idea more quickly than it did the first time and started working individually sooner. In contrast, Team B worked together more in the F2F than in the DIS setting: about 48% of the entire design process in the F2F setting and about 40% in the DIS setting. Both teams worked together in
the F2F setting an average of about 42% of the time and in the DIS setting about 55%. That is, teams had more time to work individually in the F2F setting.

3. Study 2

3.1 Experimental Design

In Study 2, the same methodology and experimental procedures as those used in Study 1 were used with two new teams of designers. However, different types of CMC tools were provided that allowed participants to share real-time information such as sketches and 3D models. Microsoft Net Meeting was introduced, which allowed the team members to sketch together using a whiteboard to share any program (e.g., 2D or 3D graphic programs, video chat, and to transfer files. Participants were required to use Unreal (CVE) and NetMeeting in the DIS setting. The teams in the F2F setting were not required to use any of the tools because we wanted to identify which tools the design teams chose to augment their collaboration.

Experimental Setup

The experimental setup of Study 2 differed from that of Study 1 in only one aspect: Whereas participants in the F2F setting were seated next to each other with their own workspaces (see Figure 1) in Study 1, participants in this setting faced each other across a table (see the top two images of Figure 11) in Study 2. Tasks 1 and 2 were identical to those in Study 1. Team C was in the F2F setting first, followed by the DIS setting. Team D was in the DIS setting first, followed by the F2F setting.

Measures

Observations focused on how much time teams worked together compared to the first study and what types of tools helped them collaborate. The "together" state was defined as the amount of time designers communicated and shared design information about their design. The "individual" state was defined as the amount of time designers worked on tasks individually [5, 8]. Using these two measures, shown in Table 5, researchers also looked at five different communication modalities for each design process: talking, gesturing, writing, sketching, and modeling. In addition, researchers determined when and what types of the CMC tools (i.e., video chat, IM, whiteboard, shared program design) the teams used and verified what types of technology the teams chose to use for collaboration (i.e., working "together"). Observer XT 8.0 was used to segment, code, and visualize the data.

3.2 Results of Study 2

Collaborative Design in a face-to-face Setting

Observation in the F2F setting focused on how members of each design team collaborated; their modes of communication and use of tools. In the F2F setting, both teams exhibited a similar number of communication modalities. As Figure 7 shows, teams engaged in talking in most parts of the task (Team C: 46% of the total; Team D: 47% of the total), and CAD tools (Team C: 36% of the total; Team D: 31% of the total). Both teams used sketching about 20% of the total time. Neither team used Unreal as a design tool in this setting. When teams talked or showed sketches, gestures played a large role in their design communication, and when they annotated and described their design ideas, they used writing on the presentation board.
Collaborative Design in a Distributed Setting

In the DIS setting, members of both teams used the NetMeeting program to collaborate on the 3D model, the whiteboard to sketch together, and video chat to see and talk to each other. As shown in Figure 8, participants spent most of their time on 3D modeling (Team C: 47% of the total; Team D: 38% of the total). They communicated through talking (Team C: 31% of the total; Team D: 38% of the total), gesturing (Team C: 5% of the total; Team D: 2% of the total), and sketching (Team C: 15% of the total; Team D: 7% of the total). While one designer was modeling in SolidWorks, the other was able to view the 3D object in a shared view. Thus team members were able to discuss details simultaneously. However, teams used less communication in the DIS setting than in the F2F setting. They used talking (35% of the total), gesturing (4% of the total), and sketching (11% of the total) in the DIS setting compared to talking (47% of the total), gesturing (14% of the total), and sketching (21% of the total) in the F2F setting.

Figure 7 The teams' design process in the F2F setting
Comparison of the Findings from Study 1 and Study 2

As shown in Figure 9, the teams in Study 2 worked longer together than the teams in Study 1. In the F2F setting, the together working mode lasted an average of 17.5 minutes longer. In the DIS setting, the together working mode lasted an average of 14 minutes longer. In addition, the teams worked together 6 minutes longer in the DIS setting than in the F2F setting in Study 2. It appears that because participants were able to see and talk to each other in the F2F setting, they were able to formulate a design more quickly than in the DIS setting.

Types of Computer-Supported Tools

CMC tools such as video chat and a webcam allowed designers to see, talk, and even share sketches (through the webcam). The whiteboard allowed real-time communication and spontaneous interactions between the designers. In the questionnaires, the teams reported that NetMeeting and the whiteboard were helpful in enabling both team members to conduct multiple tasks at the same time, although technical difficulties were somewhat problematic.
Specifically, the NetMeeting Shared program helped team members to share 3D models so that they were continuously able to see their teammates' screen on their own screen, make suggestions, and review each other’s work.

4. Discussion

Design teams in Study 1 exhibited a similar pattern of collaboration strategy in both F2F and DIS settings. Team members worked together less than 50% of the overall work time, on average. In Figure 10, the yellow bar shows the time “working together,” and grey bar shows the time “working individually.” During Study 1, design team members divided the work among themselves and then worked individually until the end of the session. This was likely because they did not have the tools to enable them to easily share design information. Study 1 suggested that a tool to support interaction and information sharing in DIS settings could increase collaboration. This proposition was tested in Study 2.

The results of Study 2 were that teams spent more time working together when using programs that supported shared sketching abilities or shared viewing of 3D objects. As Figure 11 shows, design teams in Study 2 worked together, not only longer, but also more continuously than in Study 1. The shared program allowed team members to work together after they divided the work between themselves.
Despite the small number of design teams, the two studies supplied information helpful to understanding how design teams collaborate with existing tools. All the design teams reported that they were reasonably satisfied with their design outcomes, the process, and communication with their teammates, and they admitted that they had fun in the sessions. However, the process of collaboration and the use of communication tools in the two studies differed significantly.

**Face-to-Face vs. Distributed Collaboration**

Studies have shown considerable differences between face-to-face and distributed collaborative design processes, specifically the use of tools in the collaborative design process, this study was no different. Team members gestured and sketched about fifty percent more in the F2F setting than in the DIS setting. As indicated by a post-task questionnaire, all participants preferred working with their teammates in the F2F setting over the DIS setting. They indicated that they were more successful at sharing design information with their teammate when face-to-face because they could easily and instantly share ideas and see each other's screens. Surprisingly, teams reported that they found the DIS setting to be a more engaging environment to work with teammates because they were "forced to be engaged" and "forced to communicate better," than when face-to-face.

An interesting difference between the results of Study 1 and Study 2 was the increase in the amount of time that the teams worked together when face-to-face. Even though the members of the teams in both studies used almost the same traditional tools such as pens and paper, they worked considerably longer (see Figure 9) in Study 2 than they did in Study 1. This was likely because of the change in seating arrangement of team members. Whereas in Study 1 participants sat at a different desk next to one another (see Figure 1), participants in Study 2 sat at the same desk facing each other (see the top two images of Figure 11). This ability to see each other's faces may have made communication and interaction less effortful.

**The Effects of Computing Technology**

One important objective of this research was to identify the technologies that facilitate collaboration between distributed team members on a design team. The shared program and the whiteboard function from NetMeeting helped the design teams to share real-time information. The studies also revealed the strengths and weaknesses of a 3D virtual environment, Unreal, on design collaboration. One of the strengths of the Unreal was that team members could convey ideas about the model using a laser pointer in the 3D virtual environment. Findings from the studies revealed that designers use gestures while describing ideas, sketches and 3D models. When sharing ideas, team members used the phrase "like this" when referring to physical (e.g., a sketch with fingers) or digital (e.g., a sketch with a mouse) information. The gesturing of visual information by a designer may be one of the most important aspects of a new 3D virtual environment that increases effective collaboration between distributed designers system. Although the CVE used in these studies did not lead to effective collaboration, several potential features such as creating virtual mock-ups for brainstorming within a virtual environment were provided by participants. Their suggestions are presented in Table 2.
Table 2. Participants' Opinions about the 3D Virtual Environment

<table>
<thead>
<tr>
<th>Current Unreal</th>
<th>Negative Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Comments</td>
<td>Negative Comments</td>
</tr>
<tr>
<td>• Laser pointer was helpful in conveying what they were referring to on the model</td>
<td>• Lack of manipulation</td>
</tr>
<tr>
<td>• Liked multiple people sitting around a model in a virtual environment</td>
<td>• Difficulty using Skype video with Unreal because it takes up the whole screen</td>
</tr>
<tr>
<td>• Easy to talk about model</td>
<td>• Lack of communication tools such as shared drawing</td>
</tr>
<tr>
<td>• Great for visualization</td>
<td>• Lack of sharing thoughts and ideas</td>
</tr>
<tr>
<td>• Real-time visualization</td>
<td></td>
</tr>
<tr>
<td>Collaborative 3D Virtual Environment System</td>
<td></td>
</tr>
<tr>
<td>• Ability to manipulate 3D model and manipulating 3D modeling together within a virtual environment</td>
<td></td>
</tr>
<tr>
<td>• An integrated 3D modeler and 2D sketching tool with an audio and a web browser to search for precedence material</td>
<td></td>
</tr>
<tr>
<td>• Ability to create virtual mock-ups for the brainstorming within a virtual environment</td>
<td></td>
</tr>
<tr>
<td>• Ability to record conversations for later use</td>
<td></td>
</tr>
<tr>
<td>• Ability to quickly store paper sketches with annotations</td>
<td></td>
</tr>
</tbody>
</table>

Additionally, the capability of importing a 3D model and manipulating a 3D model together within a virtual environment could be an important feature within a 3D virtual environment program. If team members could manipulate their 3D files at the same time, this system for collaboration might become a dynamic and effective tool for designers to share ideas. Participants indicated that they wanted to be able to, not only share a 3D object model, but also manipulate it simultaneously in a shared view.

4. Conclusions and Future Work

Study 1 and Study 2 provided useful information about how technologies, such as CMC and CVE, have an effect on collaboration in F2F and DIS settings. The results demonstrated that the shared program and the whiteboard function from NetMeeting helped members of the distributed design teams to share information and increase the amount of time they worked together. Sitting at the same desk facing each other in the F2F setting also increased the amount of time team members worked together compared to when they were sitting at separate desks next to each other. It thus appears that when team members are more easily able to observe each other’s work, either through computer tools or through sitting placement, they tend to collaborate more. The CVE has the potential to be an effective collaboration tool if it could provide better sharing capabilities, such as the capability to manipulate 3D models in real time. Further research is needed to validate a recommended system for design collaboration that supports interaction and information sharing.

5. Acknowledgements

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6. References


