Evaluation and Student Perception of Augmented Reality-Based Design Collaboration

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Abstract

Interdisciplinary collaboration is an important aspect of industrial design, which involves interaction with other disciplines, such as engineering and management. The main purpose of this study was to investigate and evaluate student interaction with an augmented reality system in interdisciplinary design teams. The result indicated that design students and engineering students tended to regard the system as more stimulating. However, design students tended to regard the system as unreliable. The result indicated that augmented reality-based design collaboration should be more intuitive, flexible, and should have much of the functionality of the current design practice, in order to provide a more satisfactory user experience.

Keywords
Augmented reality, design education, ARToolKit

1. Introduction
The purpose of design education is to nurture “designerly” abilities: to “image” in our minds things we have experienced and also that we haven’t; our ability to manipulate those images, both in our minds and through externalized actions such as talk or drawing; and our ability and determination to utilize imaging and modeling of ideas to create new future realities (Stables 2008). Nowadays, computer aided design has become a recognized technique for industrial designers. Various software and hardware are used to support different design activities from visualization to communication. As design becomes more interdisciplinary, it is necessary for design educators to match up with the development of computer technology by integrating digital media in the design communication process. However, the success of interdisciplinary design collaboration depends on the smoothness of communication among various disciplines. In this study, an augmented reality system was applied to the communication process in interdisciplinary design teams. The purposes were as follows.

- To observe the interaction among students of interdisciplinary design teams.
- To implement an augmented reality system in interdisciplinary communication.
- To reflect students’ attitude towards the use of the augmented reality system.

2. Literature Review

2.1 Augmented Reality
Designers are always interested in introducing more productive and effective methods for improving communication in the design process. The emergence of technological innovations such as web-based virtual environments has provided the potential for such a purpose. Virtual applications can provide the tools to allow users to communicate in a quick and happy mode by playing in virtual environments (Pan et al. 2006). One of the most promising technologies that currently exist is augmented reality (AR), which is a variation of virtual reality (VR). VR technology completely immerses a user inside a synthetic environment. While immersed, the user cannot see the surrounding real world. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or mixed with the real world. Therefore, AR supplements reality, rather than completely replaces it. Ideally, it would appear to the user that the virtual and real objects coexist in the same space (Azuma 1997). The main advantage of using AR is that users can see and manipulate 3D objects in real time without the knowledge of traditional 3D

modeling software. By perceiving and experiencing directly in three dimensions, spatial relationships could be comprehended better and faster than with traditional methods (Kaufmann and Schmalstieg 2003).

Previous works (Liarokapis et al. 2002; Fjeld et al. 2003; Kaufmann et al. 2006; Alcañiz et al. 2010) focused on presenting 3D graphical models to students, in order to assist them with complex spatial problems. However, the application of AR in design education was little explored (Liarokapis et al. 2002). Chatzimichali et al. (2011) provided a theoretical framework to experiment with novel collaborative tools like augmented reality in the product development setting. Their core argument was that augmented reality technologies acted as a catalyst to the communication between the various stakeholders. Caruso and Re (2010) identified that, in the design review phase, the AR was very useful because the designer could evaluate rapidly many different designs of the product without the need to create a physical prototype for every final products. Lee and Park (2005) proposed augmented foam, which applied augmented reality technologies to physical blue foams. Designers were able to inspect and evaluate the design alternatives interactively and efficiently. Djajadiningrat et al. (2000) proposed useful principles for the design of augmented reality from the viewpoint of product design to avoid pitfalls, which included the use of proper visual design techniques and the understanding of the user's experience. They also suggested that industrial designers should participate in the technical development of augmented reality.

2.2 Design Collaboration

Interdisciplinary design, which is common in a modern design firm, is often considered to be pivotal in the innovative design process. Today's design problems are often interdisciplinary. Designers from many different domains must cooperate to reach a solution (Burns and Vicente 1995). As a result, design seems to have become even more interdisciplinary than in the past (Grudin and Poltrock 1989). An interdisciplinary team is an entity that has a structure, a definition, a direction, an identification, and group energy or synergy (Francis and Young 1979). Interdisciplinary team functioning is also a process of development and change. However, within the interpersonal team perspective, three factors appear to promote or hinder interdisciplinary activities: goal and role conflict, decision-making, and interpersonal communication (Mariano 1989). Interdisciplinary design has created challenges in design collaboration due to the difficulty in communicating and coordinating across disciplines (Curtis et al. 1988). Team members from different disciplines may view and solve the same problem from different perspectives, with their own unique method and language, which may create barriers to information sharing (Phuwanartnurak 2009). To improve design communication in interdisciplinary collaboration, information sharing across disciplines needs to be supported.

3. Research Design

3.1 Interdisciplinary Design Teams

This study compared interdisciplinary design collaboration by configuring a simple AR environment, and traditional 2D drawings were also used in media presentation. The test subjects were specially chosen to represent interdisciplinary team members in different areas, such as design, management and engineering. Each team included three students from different backgrounds, and there were a total of six teams participating in interdisciplinary design collaboration, as shown in Table 1.

Table 1: Participants' background

Areas of specialty	Management	Design	Engineering
	6	6	6
Gender	Male		Female
	10		8
Educational background	Bachelor	Master	PhD
	7	10	1

In order to make the experiment run smoothly, the topic of the study and the roles of each team member were introduced at the beginning for the students' understanding of their roles in assisting each team to achieve its stated purpose. The procedure of the experiment was described to facilitate the students' preparation and understanding of intended performance. The duration of each team session was 40 minutes by default. Each team was provided with AR media and traditional 2D drawings, and there were two design projects for discussion. During each discussion, a team member with management background controlled the timing for each team. After the discussion of a project, team members were interviewed in a focus group for their experience and preference of using traditional and AR media. The interview time was between 15 to 20 minutes. Each interview was recorded and transcribed, and was checked by interviewees for subsequent analysis.

3.2 The AR System for Interdisciplinary Design

The system was based on the augmented reality application ARToolKit, which is a tool for developing AR interfaces using computer vision based tracking with square markers. It provides AR tracking, virtual object overlay and simple interaction techniques. It is one of the leading open-source AR programming libraries and runs on Windows, Linux and Mac OSX operating systems. The only hardware required is a computer and a low-cost USB web camera. The requirements for a marker is that it must be square, must have a continuous border and the image inside the border must be asymmetric. The visual marker is detected in a live video stream, extracting the 3D position of the marker and its rotation.

The system utilized collaborative augmented reality as a medium for presentation, and used 3D models to facilitate design collaboration. The system included a notebook and a camera for the detection of printed markers. By changing, moving and rotating the markers, 3D models were generated, superimposed and displayed on the screen. The system configuration is illustrated in Figure 1.

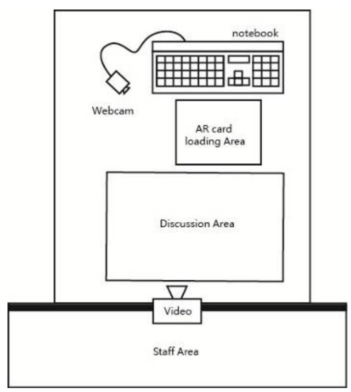

Figure 1: The collaborative augmented reality system

4. Results and Discussions

The system was evaluated by team members and the questionnaire for user interaction satisfaction (QUIS) was used to measure the quality of user interaction with the system. The overall mean for all questions was a 5.09 on a 1-9 Likert scale. The scale was arranged so that positive adjectives anchored towards 9 and negative towards 1. A one-way ANOVA was used to test for differences among students of three areas of specialty: design, management and engineering. The result is shown in Table 2. There were significant differences in overall reaction to the system (dull/ stimulating) ($p = 0.047$) and system reliability (unreliable/ reliable) ($p = 0.044$).

Table 2: One-way ANOVA of the QUIS

No.	QUIS items	P	F test	Mean
	Overall Reaction to the System			
1	terrible/ wonderful	0.847	0.168	4.83
2	difficult/ easy	0.451	0.841	5.06
3	frustrating/ satisfying	0.912	0.093	4.78
4	inadequate power/ adequate power	0.596	0.536	4.67
5	dull/ stimulating	0.047*	3.78	4.67
6	rigid/ flexible	0.943	0.059	5.61
	Screen			
7	Reading characters on the screen (hard/ easy)	0.847	0.168	5.61
8	Highlighting simplifies task (not at all/ very much)	0.536	0.65	5.39

9	Organization of information (confusing/ very clear)	0.487	0.759	4.39
10	Sequence of screens (confusing/ very clear)	0.809	0.215	4.65
	Terminology and System Information			
11	Use of terms throughout system (inconsistent/ consistent)	0.615	0.503	4.47
12	Prompts for input (confusing/ clear)	0.557	0.61	5.12
13	Position of messages on screen (inconsistent/ consistent)	0.905	0.1	4.82
14	Computer informs about its progress (never/ always)	0.849	0.166	5
15	Error messages (unhelpful/ helpful)	0.728	0.325	5.06
	Learning			
16	Learning to operate the system (difficult/ easy)	0.113	2.557	5.65
17	Exploring new features by trial and error (difficult/ easy)	0.588	0.552	5.53
18	Performing tasks is straightforward (never/ always)	0.777	0.256	5.65
19	Remembering names and use of commands (difficult/ easy)	0.794	0.235	5.65
	System Capabilities			
20	System speed (too slow/ fast enough)	0.865	0.146	5.82
21	System reliability (unreliable/ reliable)	0.044*	3.158	4.88
22	System tends to be (noisy/ quiet)	0.553	0.619	5.18
23	Correcting your mistakes (difficult/ easy)	0.976	0.024	4.76
24	Designed for all levels of users (never/ always)	0.279	1.402	4.88

* $p < \alpha = 0.05$.

Further analysis of overall reaction to the system (dull/ stimulating) with a post-hoc LSD-test revealed differences between students as shown in Table 3. There were significant differences between design students and management students (p = .049), between management students and engineering students (p = .021). Design and engineering students tended to regard the system as more stimulating.

Table 3: Post hoc tests of overall reaction to the system (dull/ stimulating)

(I) Specialty	(J) Specialty	Mean Difference (I-J)	Std. Error	Significance	95% Confidence Interval	
					Lower Bound	Upper Bound
Design	Management	.83333*	.38968	.049	.0027	1.6639
	Engineering	-.16667	.38968	.675	-.9973	.6639
Management	Design	-.83333*	.38968	.049	-1.6639	-.0027
	Engineering	-1.00000*	.38968	.021	-1.8306	-.1694
Engineering	Design	.16667	.38968	.675	-.6639	.9973
	Management	1.00000*	.38968	.021	.1694	1.8306

* The mean difference is significant at the .05 level.

Table 4: Post hoc tests of system reliability (unreliable/ reliable)

(I) Specialty	(J) Specialty	Mean Difference (I-J)	Std. Error	Significance	95% Confidence Interval	
					Lower Bound	Upper Bound
Design	Management	-1.70000*	.70789	.031	-3.2183	-.1817
	Engineering	-1.36667	.70789	.074	-2.8849	.1516
Management	Design	1.70000*	.70789	.031	.1817	3.2183
	Engineering	.33333	.67495	.629	-1.1143	1.7810
Engineering	Design	1.36667	.70789	.074	-.1516	2.8849
	Management	-.33333	.67495	.629	-1.7810	1.1143

* The mean difference is significant at the .05 level.

Further analysis of system reliability (unreliable/ reliable) with a post-hoc LSD-test revealed differences between students as shown in Table 4. There was a significant difference between design students and management students (p = .031). Design students tended to regard the system as unreliable.

Comments and question ratings on the QUIS indicated areas for interface improvements. The quantitative questionnaire results were investigated further by the focus group and interviews. The results were positive, based on feedback from team members. Students suggested several enhancements such as multitasking and interdisciplinary collaboration. Some students also indicated that the idea of using augmented reality to identify promising concepts might not be easy for novice users to grasp.

Feedback from the focus group revealed the following advantages of applying augmented reality to design collaboration:

- AR-based models are three-dimensional and can be moved in multi-directions conveniently.
- AR-based models can replace physical rough models.
- AR-based models can be rotated freely.
- AR-based models can be manipulated instantaneously to stimulate more design thinking than two-dimensional drawings.
- AR-based models increase interactivity in design collaboration.
- AR-based models facilitate the understanding of spatial problems.

The system uses AR as a 3D model manipulation tool and the focus is laid on the collaborative aspect of interdisciplinary group discussions. The system can fill in the gap between communication and lack of collaborative support by offering a way to visualize 3D models that are not only tangible, but also can be interacted with. Interdisciplinary team members can view such models concurrently from different angles on a face-to-face basis. Presenting 3D models in the AR system can stimulate instant and intuitive interactions that encourage exploration of new ideas. Material and colors of models can be changed instantaneously to reduce misunderstanding in communication. Overall, the system brings about joys in designing, the capacity to realize designs, and a sense of accomplishment.

Therefore, AR may have the ability to change traditional design methods by offering an effective communication platform. It can visualize concepts that lead to an improvement in team members' comprehension. Another import aspect is that interactivity is added to the communication process and is important for information sharing among team members. Support for an AR system requires fluent interaction between team members and knowledge in a way that does not impede the process of design collaboration. As the process becomes more interactive, informative and expressive, students can benefit from such an improvement in many areas.

5. Conclusions

The result indicated that the use of augmented reality to support interdisciplinary design collaboration could be beneficial to practical teamwork. Design students and engineering students tended to regard the system as more stimulating. However, design students tended to regard the system as unreliable. Therefore, the system should be intuitive to use, flexible, and should have much of the functionality of the current design practice, in order to effectively improve design outcomes and to shorten communication time. Intuitiveness is important in the context of both output and input devices. Without intuitiveness, input devices might mislead users and reduce design effect while output devices can not improve design ability simply by digitizing traditional design techniques. Substantiating spatial and abstract concepts in system output is important to successfully increase team members' outcomes in interdisciplinary design collaboration.

Augmented reality can present objects in a more intuitive way and is suitable for developing 3D communication environment for design, and allows students to explore the full potential of design concepts, to evaluate 3D objects before anything is physically built. Students want to be empowered by technology and to apply their knowledge and experience to communicate designs that lead to improved results and greater personal satisfaction. The system can thus build a future in which students will experience competence, clarity, control, comfort, and feelings of mastery and accomplishment.

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