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# Exploring the role of large-scale immersive computing environments in collaboration between engineering and design students

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**Exploring the role of large-scale immersive computing environments in  
collaboration between engineering and design students**

by

**Meisha Nicole Rosenberg**

A thesis submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of  
MASTER OF SCIENCE

Major: Mechanical Engineering and Human-Computer Interaction

Program of Study Committee:

Judy M. Vance, Major Professor

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Iowa State University

Ames, Iowa

2015

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## DEDICATION

I dedicate this work to God who has been my eternal rock and source of refuge. Also to my wonderful and amazing husband. He is my constant inspiration in the pursuit of knowledge and has always brought out my very best. His unconditional love and support has helped to make me the woman that I am today.

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## ABSTRACT

In order to solve the engineering challenges of today, multidisciplinary collaboration is essential. Unfortunately there are many obstacles to communication between disciplines, such as incongruent vocabularies and mismatched knowledge bases, which can make collaboration difficult. The silos separating disciplines, created through focused educational curriculum, are also a large barrier. During their education, designers and engineers are encouraged to employ specific methods unique to their discipline to share ideas with their peers. In many cases, however, these methods do not translate between disciplines, making it challenging for two groups to exchange ideas and perspectives effectively. There are, however, some tools that have emerged to help bridge the gap between designers and engineers.

Currently, the most pervasive solution to these challenges is Computer-Aided Drafting (CAD) software. This software is used by both engineers and designers, allowing both groups to design and evaluate models in a common medium. This makes it decidedly easier for these two groups to collaborate with each other. However, CAD has its own limitations. Navigating in a three-dimensional environment with two dimensional input devices is unnatural and imposes an additional physical and cognitive load on the user. Desktop screens also limit decision-making capabilities due to their small size and the potential to create distorted impressions of size and scale of models larger than the computer screen.

Large-Scale Immersive Computing Environments (LSICEs) improve upon the benefits of CAD software. They provide users with the ability to not only visualize their designs three dimensionally, but also allow for natural interactions with 3D models and the ability to view a design as the designer had intended, in true scale. This can improve the ability of users to collaborate in a number of different ways. The natural interaction interface allows students to

focus on sharing ideas with their collaborators. Additionally, the common medium makes it much easier for the two groups to communicate with each other, eliminating one of the main obstacles to interdisciplinary collaboration in education.

This research seeks to gain a better understanding of how design and engineering design students use LSICEs to collaborate with peers, both within and outside of their discipline. Two studies were conducted. In the first study, two different classes of students used a LSICE as a tool during their design process. The first class was a design class that utilized the LSICE as a part of three design projects throughout the semester. The second class was a sophomore engineering design class. These students also used the LSICE as a part of their design process, however these students used the virtual environment over the course of a single semester-long design project. Students were given a short survey at the end of their experiences in the virtual environment. From this study, some interesting results emerged. Both groups of students indicated that the virtual environment was a benefit to their design process, regardless of background or time spent in the space. Statistical analysis of the students' responses revealed no significant differences between the two groups of students.

The final study brought engineering and design students together to complete a design review task within the LSICE. This study was conducted in order to evaluate the role that LSICEs play in facilitating collaboration between engineers and designers. Upon conclusion of the design review, students were given a survey to gather information of their perceptions of the virtual environment in visualizing designs, communicating with their peers and interacting with designs. From this study it became quite clear that students find LSICEs to be effective in facilitating communication between disciplines. Additionally, the majority of students commented on the positive effect that the natural interaction interface had on their ability to evaluate the design.

Throughout each of these studies, common themes emerged between both groups. Student responses show many perceived benefits to LSICEs which have the potential to inspire student-driven interdisciplinary collaboration. Participants found that the environment improved their

ability to communicate, whether it be with peers within their disciplines or when working in interdisciplinary groups. Students also found that interacting in the environment in a natural way improved their ability to make judgments about spatial relationships among components.

The results from this research are quite promising. Providing students with collaboration tools that support natural human interaction with CAD models of real size has the potential for greatly improving a student's educational experience. Manipulating full size CAD models encourages students to visualize the size and shape of the final design before it is built. Seeing the designs in full scale allows everyone on the team to experience the design and provide their input into the design discussions. This research continues an effort in academia to leverage cutting edge technology to improve student learning by providing unique opportunities to interact with peers in design teams, promoting graduates who are well equipped to work effectively across disciplines to address the challenges of today.

## CHAPTER 1 INTRODUCTION AND MOTIVATION

A large focus of engineering education is on learning technical fundamentals, such as thermodynamics, manufacturing, statics and mechanics. However, the ability to communicate and function as an effective team member is also recognized as an important part of engineering education.

In 1996, the Accreditation Board for Engineering and Technology (ABET) approved the Engineering Criteria 2000. With its adoption, the accreditation criteria moved from a focus on requiring a given number of credits in key subject areas to a skills-based assessment approach that outlined mastery of technical skills and professional skills. Among other items, the list of ABET criteria included (1) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; (2) an ability to function on multidisciplinary teams; and (3) an ability to communicate effectively (Yeargan et al., 1995). There have been many changes to the accreditation criteria over the past 15 years, however, these basic goals have been maintained (ABET, 2014). In addition to ABET, several other national agencies such as the National Science Foundation (NSF, 1997) and the President's Council of Advisors on Science and Technology (Holdren et al., 2012) that have highlighted the strong demand in industry for graduates who are well equipped to perform on teams. The challenge for today's educators is how to provide curriculum that achieves these goals.

Design thinking has been explored as a tool to equip students with the necessary skills. As early as 1996 Simon proposed that design thinking is a core fundamental of engineering and design education (Simon, 1996). Sheppard (2003) and others have shown that design thinking skills contribute greatly to enhancing the ability of engineering graduates to address today's challenges in addition to helping universities to meet the goals of ABET 2000 .

There has been a shift in the types of challenges that are faced by industry today. Radical growth in human knowledge has fueled this transformation. Moore's Law, actualized by Gordon Moore in 1975 (Moore, 1975), describes the trend in which capabilities of computer circuits double each year. Buckminster Fuller described a similar trend in his book '*Critical Path*' (Fuller, 1981). His *knowledge doubling curve* is the curve that represents the rate at which human knowledge doubles. According to Fuller, between 1600 and 1900, knowledge doubled roughly once every 100 years. Throughout the 20th century, this rate increased exponentially. He predicted that by the turn of the century, human knowledge would double once every 18 months. Many of the accomplishments of the 20th century, such as the lunar landings, building of the Hoover Dam, and implementation of a national interstate system, are complex systems that require the work of many design engineers. The challenges of today, such as cyber-security and managing the nitrogen cycle, have an added level of intangibility that has increased the complexity of these problems. The problems of today are more abstract and more interdisciplinary in nature than ever before.

These technological advancements have had a substantial impact on education (Greenstein, 2012). Students today utilize computers and software as primary design mediums. Virtual reality, once an experience only described in science fiction literature, is now available to students through a variety of multi-modal devices. Immersive environments that provide virtual reality experiences allow students to see their computer generated designs in full size before building a first prototype. They also allow groups of students to discuss product designs while interacting with the computer models using natural human motions. Because of this capability, virtual reality has the potential to facilitate multidisciplinary collaboration, while simultaneously engaging students in design thinking.

Effective communication across disciplines is often challenging. Collaboration between designers and engineers is not an exception. Misunderstandings often arise as a result of incongruent goals. Many times, the intention of designers is to convey the aesthetic qualities of a design, while engineers is to focus on the functional capabilities and motion of their designs. There are many tools and methods that are employed to achieve these goals, however; oftentimes they are used exclusively by one group or the other. For instance, a designer may begin brainstorming

by sketching out rough shapes in a notebook, while an engineer might start out by generating a list of functional requirements. Physical prototyping and Computer-Aided Drafting (CAD) software are methods used by both designers and engineers in the early stage of design. Each tool has its unique advantages and disadvantages.

Prototypes are preliminary models created in order to gain insights about a design within a variety of contexts. By creating a prototype, the designer is able to gain a better understanding of the scale and spatial relationships of a design. Prototypes are used by both designers and engineers as a means of sharing ideas with others. However, designers and engineers often have different goals when constructing prototypes. Designers might make a prototype to get a sense of the look and feel of a design. An engineer might create a prototype in order to conduct a functional test of the product's design. Unfortunately, current prototyping methods fall short of achieving these goals on both accords. Early stage prototypes are typically created with whatever materials are available, such as cardboard or clay. This sometimes results in creations that hardly represent either the aesthetic or the functional qualities of the design. High fidelity prototypes created in the later stages of design are often costly and time intensive to create. With the significant advancements in computer-aided-design tools, engineers and designers have turned to CAD modeling to create prototypes of their designs.

CAD models, unlike physical prototypes, can quickly be modified through a series of simple computer commands. Using CAD software, designers can create visual renderings of designs that show the detailed properties of a design, such as how the aesthetics will be affected by certain lighting conditions, or how different colors will affect the appearance of the design. CAD can also be used effectively by engineers to simulate the functionality of the design, allowing them to gain insights about how different parts within the design will interact while in motion.

One advantage of building physical prototypes over creating CAD models is that oftentimes they can be built on a one-to-one scale. CAD models, on the other hand, are constrained to be visualized by the size of the computer monitor. Users can zoom in to look at fine details in a CAD model, but getting a sense of the overall size of the design can be difficult. Additionally, using 2D interface devices, such as a mouse and keyboard, interacting with 3D CAD models can be challenging. This use of 2D input devices to interact in a 3D environment places an

added physical and cognitive burden on the user, sometimes limiting their ability to effectively evaluate their designs and to interact with them naturally. In summary, CAD models, when primarily used by engineers, are easy to modify to explore many design options and physical prototypes, and when primarily used by industrial designers, allow users to experience one-to-one scale models.

In most cases, engineers and designers have learned to use both prototyping and CAD effectively within their given discipline. However, issues arise when these groups begin to work collaboratively across disciplines. Many of these challenges stem from a mismatch in background knowledge as well as differences in communication styles. These challenges can create barriers and stifle collaboration between engineers and designers during the design process. In order to meet the growing demand for complex product design, new tools for cross-disciplinary collaboration are needed.

Immersive Computing Technology (ICT) is one tool that shows promise in fulfilling this need. ICTs are tools that can simulate physical presence in places in the real world or imagined worlds by stimulating human senses such as taste, sight, smell, sound, and touch. These include Head-Mounted Displays (HMDs), Augmented Reality (AR), and Large-Scale Immersive Computing Environments (LSICEs). LSICEs are particularly well suited to meet the needs of cross-disciplinary collaboration in design teams. LSICEs are virtual reality facilities consisting of large projection screens that can display life-size virtual geometry in 3D. Position tracking systems provide real-time position and orientation data that is used by the simulation to update the computer images in an effort to simulate viewing the real world. Natural interaction with the geometry is accomplished through the use of a variety of devices including wands, haptic devices, and gloves. Audio may also be used to add in the experience.

These facilities allow engineers and designers to see their design in full scale. This provides users with the ability to evaluate their designs in a more realistic context. In these environments, surfaces and textures are rendered in a lifelike manner. Aesthetic qualities of a design can be evaluated within environmental contexts. By visualizing models in one-to-one scale, designers can gain insights into the implications of the spatial relationships. Similarly, engineers can evaluate mechanical properties by incorporating information about motion and

forces. Using this data, simulations such as Computational Fluid Dynamics (CFD) or Finite Element Analysis (FEA) can be conducted and visualized within the same environment as the geometry. Multiple simulations can run and be modified on the fly without the need for additional equipment.

LSICEs can be utilized to help both designers and engineers communicate their ideas more effectively and as a result collaborate more successfully. Teaching these tools early in the education process while students are still building their problem solving toolboxes allows them to incorporate this knowledge into other aspects of their education. Learning to communicate is key to enabling them to learn to work with each other. The use of virtual reality to enable innovative design experiences is a promising instrument for educating the next generation of engineering and design students.

The goal of this research is two fold. First, this research seeks to understand what perceived effect the LSICEs has on students' abilities to generate and communicate their ideas. Second, we hope to learn about how the use of LSICEs can affect the collaborative design process between engineering and design students.

This thesis is organized as follows. Chapter 2 will provide background and motivation for the research that was conducted. Chapter 3 will discuss a study in which two classes of students in the College of Engineering and the College of Design use an LSICE as a part of their courses. Chapter 4 details a study in which engineering and design students worked together to complete a collaborative design task within the virtual environment. Finally, Chapter 5 discusses the conclusions and the future work resulting from this research.



## CHAPTER 2 BACKGROUND

The ABET 2000 Criteria have driven the need to educate engineering students beyond the fundamental engineering principles typically associated with engineering to include valuable professional skills such as the ability to communicate and function collaboratively on a team. As multidisciplinary collaboration becomes increasingly prevalent, these skills become more critical. Several approaches have been developed and implemented in an effort to meet the criteria set forth by ABET. These programs have shown reasonable success in teaching students to apply knowledge from other classes to real world challenges. However, collaboration often becomes a peripheral objective. Furthermore, when collaborative education is employed, it is commonly within the isolated silos of respective disciplines.

This research seeks to understand how LSICEs can be used to supplement current instructional methods in order to engage students in multidisciplinary collaboration and provide a well rounded instruction of the key skill sets identified by ABET. This section will discuss the background of current practices such as Project-Based Learning and design thinking. In addition it will discuss the previous applications of simulations within design education and how they can be tied into the use of PBL learning in order to provide engaging educational experiences.

### 2.1 Project-based learning

Many different pedagogies have been studied in an effort to learn the best way actualize engineering design education in the classroom. These include the constructivist approach (Jonassen et al., 1993), teacher-directed learning, and studio experiences (Lee, 2009). Many of the methods that are currently practiced involve Project-Based Learning (PBL). In its essence, PBL is a student driven approach to teaching in which students engage in learning by asking questions and finding solutions to real life challenges (Bell, 2010). PBL is grounded in both

the constructivist and situated learning theories. Situated learning theory can be described as the philosophy that learning is influenced by the situation in which learning takes place (Greeno et al., 1993). Constructivist theory is based on the central ideas that learners play an active role in constructing their own knowledge and also that social interactions are a key part of this construction (Bruning et al., 1999). In short, PBL is, “a way of constructing and teaching courses using problems as the stimulus and focus for student activity” (Boud and Grahame, 1998). While there is not a specific set of guidelines for how to implement PBL in the classroom, there are six characteristics of PBL that have been widely agreed upon (Bell, 2010; Barrows, 1996; De Graaf and Kolmos, 2003):

1. **Learning is Student-Centered** Students are responsible for identifying their own learning needs and executing the necessary steps to make it happen.
2. **Learning is Collaborative** Students work together in groups of three to five to accomplish learning objectives.
3. **Teachers Play the Role of Facilitators/ Mentors** The role of the teachers to encourage students and serve as a reference rather than providing factual lecture-based knowledge.
4. **Learning is Problem-Based** Problems are presented to the students in the same context as they would be in the real world.
5. **Problems are Used to Develop Problem Solving Skills** The problems presented to the students are structured such that they encourage the students to use critical thinking in order to develop a solution.
6. **Learning is Self Directed** Students are expected to gather knowledge through their own study and research.

PBL has become a widely applied pedagogy for design education at several institutions as a means to equip students with advanced professional skills while instilling core technical knowledge. Documented use of PBL pedagogy began over 45 years ago. This approach originated

out of the Medical Doctor program at McMaster University in Canada during the late 1960's (Neufeld and Barrows, 1974). Prior to the adoption of PBL, most instruction was lecture-based, requiring students to memorize large quantities of facts and figures and then apply them within the context of closed structured problems. In 1976, Aalborg University in Denmark became the first institution to be founded on the pedagogical premise of PBL (Luxhoj and Hansen, 1996). Not long after the release of "The Report of the Panel on the General Professional Education of the Physician and College Preparation for Medicine" (Muller, 1984), the medical community began to readily employ PBL in instructing medical students through nearly all aspects of medical education (Delisle, 1997; Barrows, 1996). More recently over the past 15 years, PBL has seen widespread adoption in the engineering, business, and the K-12 education systems.

It been used extensively within the design engineering community, particularly through senior design capstone courses. These capstone courses are culminating experiences in which students are required to bring together all of their engineering skills to complete a team design project. Over the years, capstone courses were transformed from relying on artificial projects created by instructors, to projects sponsored by industry. Oftentimes these industry-student collaborations incorporate face-to-face meetings between students and participating industries. The success of capstone design classes later inspired the introduction of similar courses into earlier stages of the curriculum.

These courses, now referred to as cornerstone design courses, are used to introduce students to the context-specific challenges that engineers face without quite the same depth as capstone courses. Many times the projects that students work on are slightly more abstract applications of real-world problems without the direct involvement of engineers in industry. These courses share many of the benefits of the more advanced capstone courses; however their primary benefit lies in exposing students to real-world engineering challenges that allow them to apply knowledge learned in their general math and physics courses (Dally and Zhang, 1993; Sheppard, 2003). Additionally, these experiences give them contact with engineering faculty that are able to provide a better understanding the challenges that engineers face in industry (Pavelich et al., 1995; Agogino et al., 2000). These cornerstone design courses are structured around

student teams. Having students work in teams early in their degree program has been shown to have a positive impact on the motivation and retention of first-year engineering students (Olds and Miller, 2004; Richardson and Dantzler, 2002) as well as increase the performance of these students (Pavelich and Moore, 1996). Additionally, PBL has been shown to have a large impact in motivating students to improve the creativity of students working in groups (Zhou et al., 2012). Project-Based Learning has since become a commonly utilized method for teaching other valuable principles in engineering education, including manufacturing and heat transfer (Koh et al., 2010; Carlson and Sullivan, 1999) as well as electronics (Lamar et al., 2012).

## 2.2 Design thinking

Another valuable tool in engineering design is design thinking. Within the field of design education, PBL and design thinking go hand in hand. Dym (2005) defined engineering design as

“a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints”.

This definition highlights the importance of user-centered critical thinking within the design process. In order to become successful in engineering design, students need to learn to think critically throughout all stages of the design process.

There are several definitions of design thinking; however, it can generally be characterized as a methodology that enlists critical thinking and inquiry to inspire solutions to design problems within a given context (Brown, 2008; Dym, 2005). Oftentimes this process is employed within a collaborative social environment using multiple iterations in order to explore a large design space and identify optimal solutions.

While design thinking has been recognized as a tool for building critical thinking skills since the early 1990’s (Rowe, 1991), it has recently seen a resurgence. As is the case in many educational practices, this revival has been fueled in large part by its adoption and rebranding

within industry (Denning, 2013). Companies such as IDEO, Apple, and Google have incorporated design thinking throughout all stages of the design process. In order for students to become competitive in these industries, it is essential that they have an understanding of how to employ design thinking to context-specific challenges.

Utilizing design thinking as a part of PBL in engineering education has had a considerable effect on how students learn. However, while these PBL courses have enhanced student interest in engineering they fall short on many accords. Much of the research that has been conducted on the effects of PBL is limited to a narrow range of specific disciplines, such as medicine, engineering, and biological sciences. There have been many cases where PBL methods from one discipline have been superimposed directly on another without consideration of the specific characteristics and needs of each leading to a mismatch in learning outcomes. Additionally, while PBL has been studied extensively within the setting of a single discipline, there is a gap in the research of the use of PBL in interdisciplinary settings.

Other drawbacks to PBL arise when scaling up for larger classes. While it can be quite effective in smaller group settings, it can be difficult to implement within large class structures due to logistical challenges and high costs (Blumenfeld et al., 1994). Technology has helped to alleviate some of these limitations and has begun to play a much more prominent role in the classroom. For the students of today, technology is incorporated into nearly every aspect of their lives (Shirazi and Behzadan, 2014). In order for instructors to effectively equip students with valuable technical and professional skills, it is critical to utilize tools that engage and stimulate students.

### **2.3 The use of technology in collaborative education**

There are many incongruities between current learning styles of the millennium generation of students and the PBL methods of the past. However, as new technologies have emerged and students have become more technologically minded, new educational methods have also taken shape that integrate creative content delivery and create learner centered environments (Monaco and Martin, 2007). By using technology in conjunction with collaborative learning, instructors are able to communicate valuable lessons through several different channels, reaching

out to students with a variety of learning styles (Felder and Silverman, 1988). Currently, this is achieved through a variety of different methods including social networking (Arnold and Paulus, 2010), and blogging (Halic et al., 2010). The accessibility of technology has also led to the widespread adoption of MOOCs, or Massive Open Online Courses (de Waard et al., 2011), in which thousands of students from across the world can enroll in a single online course for little or no money.

While collaborative learning has been shown to be quite effective in improving learning, effectively employing collaboration in education involves more than simply putting several people in a room together and giving them the same task. In order for collaboration to be effective, students must learn to communicate with each other and have a common focus and goal (Ackerman et al., 2007).

Even before the value of collaboration was addressed by ABET, there was significant research highlighting the value of collaborative learning in the classroom. The benefits of collaboration in education are numerous. Within online education in particular, collaborative learning environments have been shown to create an increased sense of social presence as well as a greater sense of attachment to the online community (Rovai, 2002). It has also been shown to be a much more effective approach to teaching than previous individualistic methods (Hiltz and Turoff, 2002). Within physical classrooms, collaboration has been shown to have a meaningful impact, improving traditional classroom education (Leidner and Fuller, 1997; Alavi, 2004) and supporting student learning (Kwok and Khalifa, 1998; Kwok et al., 2002). These improvements in learning stem from the increased socio-emotional advantage gained by students working in a collaborative environment (Webb, 1989; Benbunan-Fich et al., 2005). Additionally, specific mechanisms such as conflict resolution, self-explanation, and internalization of knowledge from other team members trigger cognitive processes that lead to improvements in learning (Alavi et al., 2002; Benbunan-Fich and Hiltz, 2003; Lim et al., 1997; Piccoli et al., 2001; Webb, 1989). Other studies have shown that collaboration in the classroom leads not only to the acquisition of higher order skills, such as critical, logical and creative thinking (King et al., 1998), but also a greater level of engagement and the ability to retain information for longer periods of time (Kirschner et al., 2009).

## 2.4 Simulations in engineering education

One technology that has shown an increasing prevalence in the classroom is Immersive Computing Technology (ICT). This includes technologies such as Augmented Reality (AR), Head-Mounted Displays (HMDs), and Large-Scale Immersive Computing Environments (LSICEs). Simulations can be characterized as computer programs intended to provide a realistic imitation of complex systems. Simulations have played an important role in engineering education since the early 1990's. It has been embraced by numerous disciplines as an effective means for educating students across a wide array of learning styles (Felder and Silverman, 1988). When used in conjunction with traditional education methods, students are able to gather the necessary information from several channels, improving their retention of the material (Bell and Fogler, 1995a). Simulations also offer the potential to address some of the higher level intellectual behaviors of Bloom's Taxonomy of learning (Anderson et al., 2001) that are often unable to be achieved by traditional instructional methods alone.

Innovations in technology have reduced the cost of simulation tools, leading to a more prominent role in the classroom. This has created many new opportunities for instructors and students alike. Within engineering education, simulations have been used to instruct students in a variety of different settings. In a study by Reamon and Sheppard (1997) students used computer simulations when designing a four-bar toggle clamp mechanism. They found that through the use of the computer software, students were able to develop a better understanding of the mechanisms, which in turn leads to better transfer of learning to other principles. Similarly, Ronen and Eliahu (2000) found that when students used a circuit simulation prior to completing in-class exercises, students demonstrated greater comprehension and understanding of the underlying principles. Bell and Fogler (1995b) used a virtual reality simulation of a chemical reactor to allow students to explore chemical reactions on a much larger scale. These tools have also been widely used within construction engineering in order to give students a

greater understanding of the temporal, spatial and logistical aspects of the construction process (Akhavian and Behzadan, 2012). Additionally, simulations have been used in systems engineering (Davidovitch et al., 2006), mechanical engineering and manufacturing (Koh et al., 2010), and agricultural mechanics (Agnew and Shinn, 1990).

Much of the research conducted on the use of simulations in engineering education is grounded in situated learning theory. Preliminary studies involving the use of simulations were optimistic about the potential for these technologies. While these studies were typically limited to simple desktop applications, many found that the use of the computer software as a supplement to lab experiences led to an improvement in completion of lab exercises (Mosterman et al., 1994) and problem solving abilities (Reamon and Sheppard, 1997).

In addition to engineering, simulations have been used in education in a variety of fields from management and business (Keys and Wolfe, 1990), to decision making in military education (Cioppa et al., 2004) and flight simulations (Hays et al., 1992). Simulations have also been effective in educating medical professionals in procedures such as surgery (Gallagher et al., 2005), anesthesiology (Abrahamson et al., 2004), and resuscitation (Tjomsland and Baskett, 2002).

As improvements in hardware have taken place, the applications of these technologies in engineering education have also progressed. In 2007, Brill and Galloway (2007) conducted a study on the attitudes towards teaching technologies in the classroom. They found that the use of technology in the classroom not only helps instructors present information to their students, but also enhances the level of student engagement. Similarly, in a study conducted by Koh et al. (2010), it was found that simulation-based learning has the potential to enhance the self-determined motivation of students while improving general learning. Since this early research, technology has enabled educators to move beyond rudimentary computer simulations towards higher fidelity Virtual Reality (VR) tools including Head-Mounted Displays (HMDs) and Augmented Reality (AR). Several recent studies have evaluated the use of these more immersive computer simulations within engineering education. In a study by Dong et al. (2013) students used an augmented reality table to discuss 3D animations of a construction scene to get a better understanding of the spatial relationships. In a study by Bastiaens et al.



(2014), it was found that HMDs created a more compelling experience for the students which in turn lead to more effective learning. In 2010, the Horizon Report (Johnson et al., 2010) identified Augmented Reality as a tool with the potential to aid in the teaching of contextual learning experiences. Several studies have shown the use of AR to be beneficial in a wide range of engineering education disciplines, including civil engineering (Shirazi and Behzadan, 2014), mathematics and geometry (Kaufmann and Schmalstieg, 2003), and distance education (Liarokapis et al., 2004; Boling et al., 2012).

Large-Scale Immersive Computing Environments (LSICEs) are one VR technology that is particularly well suited for collaborative design work. LSICEs are virtual reality facilities consisting of large projection screens that can display life-size virtual geometry in 3D. Position tracking systems provide real-time position and orientation data that is used to update the computer images in an effort to simulate viewing the real world. Natural interaction with the geometry is accomplished through a variety of devices including wands, haptic devices, and gloves. Position tracking of these devices allows users to reach out and manipulate virtual objects using natural 3D motions. Audio may also be used to add to the experience. Currently, LSICEs have seen notable adoption at many educational institutions including the C6 (Kihonge et al., 2002) and METaL (Pavlik et al., 2013) at Iowa State University, Immersia 3 (Pontonnier et al., 2014) at The University of Rennes, CAVE2 (Febretti et al., 2013) at the University of Illinois at Chicago, AlloSphere (Amatriain et al., 2009) at the University of California, Santa Barbara, StarCAVE (DeFanti et al., 2009) at the University of California, San Diego, Reality Deck (Papadopoulos et al., 2015) at Stony Brook University, and EVE (GeoVisionary, 2011) at Birmingham City University.

These environments present numerous benefits. Using an LSICE, a design team can visualize designs in full-scale while manipulating them through natural interactions. With the use of these systems, both designers and engineers can come together to communicate their ideas. This technology has already been widely implemented in several industries, including John Deere and Ford (Luecke, 2012; Noon et al., 2010; Ford, 2013) and is becoming increasingly prevalent.



Figure 2.1 Large-Scale Immersive Computing Environments (LSICEs)

Many researchers have studied how users separated by time and space use LSICEs to work together (Rosenman et al., 2007); however in these studies, only a single user is present in the environment at a given time. Studies such as the one conducted by Montoya et al. (2011) highlight the importance of interacting with 3D models. Another study at the SEA Lab at Penn State (Messner et al., 2003) found that LSICEs are particularly useful in helping students to understand size and scale.

Within engineering education, simulations have been used in a very passive capacity (Bell, 2010)]. These simulations are similar to large, 3D power point presentations which are typically pre-constructed in order to teach students about a static concept or principle. In these cases, the students are shown a pre-constructed visualization that is marginally more immersive than a 3D movie. Additionally, while these simulations may be visually immersive, they do not allow students to interact with the rendered geometry. These tools provide a much more engaging experience than a typical lecture hall; however, it may not motivate students to apply critical thinking or test their abilities to communicate with their peers.

LSICEs have extensive implications for both faculty and students as a technology to support Project-Based cornerstone and capstone courses. Three-dimensional visual representations of designs are valuable at all stages of the design process. Early on, designers consider multiple concept alternatives by trading off design attributes, such as weight, material, and cost. These

trade-offs are the critical decision junctures at which true design cognition and critical thinking is applied. Immersive computing environments offer unique opportunities to visualize and interact with the design attributes of a design in 3D, allowing all aspects of the design to be evaluated, including characteristics such as size and scale, all within the appropriate context. Size and scale are critical features of a design. However, many designers are limited by what can be displayed on a computer screen. For instance, when designing a new building or a house, it is challenging to understand the impact the addition of 100 square feet may have on the ambiance of a room when looking at a model displayed on a 22 inch monitor.

While these studies highlight the benefits of using LSICEs in engineering education, they do not evaluate the role of LSICEs in collaboration between students. This research seeks to uncover students' perceptions of the effects of LSICEs on collaboration with their peers both within the same discipline and across disciplines.

## **2.5 Using LSICEs to supplement PBL and design thinking**

The focus of many of these studies has centered on improving engagement and motivation of students in the classroom; however, there has not been much research into the use of ICTs as a tool to teach interdisciplinary collaboration. LSICEs are ideal for creating a collaborative environment in which students can learn to communicate and work effectively on teams. This research seeks to understand how LSICEs can be used to help engineering and design students collaborate within the context of multidisciplinary design. Towards this goal, two studies were conducted.

The first study evaluated how both engineers and designers use this technology to collaborate within their respective peer groups, with the goal being to improve not only how this technology is integrated into the curriculum, but also to understand what improvements could be made in order to better facilitate the interaction in the environment.

The second study brought together groups of engineering and design students to complete a design review task collaboratively. The objective of this study was to learn how these two groups communicate with one another within the physical space of the environment and how the technology affects their ability to collaborate with one another.

The results have dramatic implications for the future of PBL in design education. Improving the ability of team members to communicate design intent has significant implications in early design decision making in the team. Using LSICEs supports and encourages rapid and multiple iteration in early stage design which has the potential to increase the development of design thinking skills. This technology has the potential to result in graduates that have a strong grasp of some of the more abstract qualities of design, are better equipped to work effectively in a team, and have advanced design thinking skills.

## CHAPTER 3 INVESTIGATING THE IMPACT OF LARGE-SCALE IMMERSIVE COMPUTING ENVIRONMENTS ON DESIGN EDUCATION

In the past, engineering education centered on technical fundamentals, such as thermodynamics, manufacturing and mechanics. However, over the past 15 years, there has been a notable shift. The ability to work effectively on a team and communicate clearly with peers is crucial for graduates today. There are many methods that have been employed in an effort to instill these skills in students. Recent advancements in technology have changed the way in which students are taught. Immersive Computing Technologies (ICT), specifically Large-Scale Immersive Computing Environments (LSICE) are ideally suited to solving these challenges.

### 3.1 Research questions

LSICEs allow instructors to combine the use of computer simulations and project-based learning to help students build valuable skills in communication and collaboration with their peers. Additionally, LSICEs also have the potential to build important critical thinking and design thinking skills, while motivating students to continue to pursue their education.

While the overarching goal of this research is to understand how LSICEs can be used to improve the design thinking and decision making skills of engineering and design students, this study was motivated by the primary research question: *What are the perceived effects of using LSICEs as a tool during the design process.* Additionally we were interested in understanding what the perceived effect of the LSICE on creativity and ideation was.

The results of this research will provide increased understanding of how students in particular utilize this technology as a part of the design process and it will provide insight into the current limitations of the environment so that future experiences can be improved.

## 3.2 Methods

In this research, two groups of students were studied as they used a LSICE as a part of their design process. This particular environment, the Multi-modal Experimental Testbed and Laboratory (METaL) is a projection-based system consisting of two projection screen walls and a projected floor equipped with stereo viewing and position tracking. The first group was a class of design students enrolled in a digital design course. Students utilized METaL for three different design projects throughout the semester. The second group of students was chosen from an engineering design class working on a single design project over the course of the entire semester. Before building functional prototypes of their designs, students used METaL to visualize 3D models of their designs. By interacting with CAD models within the virtual environment design iterations could be completed frequently and without the time and monetary investments of building multiple prototypes. At the end of each of these courses, both groups of students were asked to complete a brief survey regarding their experiences. The survey consisted of three seven-point Likert scale questions and three open ended-questions in which students were invited to share their thoughts about the use of the LSICE.

### 3.2.1 Participants

For this research, data was collected from two different classes of undergraduate students at a large, Midwestern university. The first was a third-year design class comprised of thirty students. While the majority of the students were studying design and architecture, engineering and communications students were also represented in this class. In total, the class included 15 design students, 13 architecture students, one communications student and one mechanical engineering student. Two of the design students had a second major in environmental studies. While these interdisciplinary students introduce some unique class dynamics, the majority of the class was composed of design students. The participants' ages were quite varied, ranging from 19 to 37 with an average age of 21.5 and included students in their sophomore, junior and

senior years of study. Of the thirty students, 21 were men and 9 were women. The class was split into eight groups with three to four students in each group. After each design project, the students were reassigned to new groups to work with.

The second pool of students was drawn from a sophomore engineering design course. Students were given an initial introduction to the Multi-Modal Experimental Testbed and Laboratory (METaL), where they received a demonstration of some of the applications of virtual reality in engineering design and were given the opportunity to interact in the environment. After this initial introduction, students were given the opportunity to bring their own CAD models into the virtual environment. There were 25 students that chose to use METaL as a part of their design process. Of these students, 23 were male and 2 were female. Their average age was 20.5 and included sophomore and junior students. The 25 students were split into five teams of five or six. They worked within these groups throughout the course of the semester.

### **3.2.2 Software and hardware**

The METaL was used to provide students with the opportunity to visualize and evaluate their designs. The METaL virtual environment consists of two walls and a floor. Three Digital Projection International TiTAN WUXGA-3D projectors display images on each of the projection surfaces of the system. An ART Track Pack 4 infrared optical tracking system is used to track the head and wand positions of a single user. Students were able to navigate around the environment and interact with objects in the scene using a Wii remote with infrared markers attached.

Students used Siemen's Teamcenter Visualization Mockup 9.1 to visualize and interact with their 3D models. In addition to walking around the physical space to explore the virtual environment, students were also able to fly around using the Wiimote wand. Individual parts of the students' designs were also able to be selected and manipulated using the position-tracked Wiimote. For this application, collision detection was not used. Additionally, students were able to move and see through their designs. Finally, all parts could be reset to their initial position using the *snapshot* feature of the software.



Figure 3.1 Multi-Modal Experimental Testbed and Laboratory (METaL)

### 3.2.3 Procedure

There was some variation in how METaL was used by each class. Within the design class, the students were assigned three projects throughout the course of the semester. The class was composed of eight small groups with three to four students in each group. Each group came into the METaL virtual environment once every two weeks to visualize their designs. During this time the students were given the ability to navigate around the virtual environment using the Wii remote. After viewing their models, they were given a week to iterate and improve on their designs. After each project, students were shuffled into new groups. At the conclusion of the semester, the students presented their final designs to the instructor within METaL. After presenting their final projects, the students were asked to complete a survey regarding their experiences in the virtual environment.

The engineering class was structured slightly differently. Rather than a series of design projects throughout the semester, the students were assigned a single engineering design project spanning the course of the entire semester. These students were introduced to the virtual environment during the exploration phase of their design projects, before any prototypes had been created. In this introduction, students were shown a demonstration of Computer-Aided Design (CAD) models rendered in the virtual environment in order to get a sense of the capabilities of



the technology. Students were then invited to visualize their own designs later in the semester after they had created 3D CAD models of their own designs. Upon conclusion of their experience in the environment, the students were given the same survey that was administered to the students of the design class.

### 3.3 Results and discussion

The survey that the students were asked to complete was comprised of two parts. In the first section, they were asked about their perceptions of the effect of the virtual environment on three aspects of the design process. They were asked to rate these on a 7-point Likert scale where one was defined as *hindered* and seven represented *improved*. Students were asked:

1. How much they felt the environment hindered or improved their ideation
2. How much they felt the environment hindered or improved their creativity
3. How much they felt the environment hindered or improved their communication

In addition to these three questions, students were also asked to answer two open-ended, short-answer questions:

1. What would you improve about the system if you could?
2. What was your favorite aspect of using METaL to visualize your designs?

The responses from each group of students have some unique attributes; however, they also share some important similarities. Overall, both of these groups reported a significant improvement in their ability to communicate ideas with their peers and to understand the spatial relationships within their designs.

#### 3.3.1 Likert responses

A summary of the statistical results from each of the groups can be found in tables 3.1, 3.2, and 3.3. Welch's independent t-tests were conducted to compare the mean responses of the design and engineering students. This test was chosen because of the unequal variances and

sample sizes of the data. Regarding the students' impressions of the immersive environment on their ideation abilities, there was not a significant difference between the responses from engineers ( $N = 25, M = 5.60, SD = 0.91$ ) and designers ( $N = 26, M = 5.73, SD = 0.78$ );  $t(47) = 0.5497, p = 0.5851$ . When considering creativity, there also was no significant difference between the responses from engineers ( $N = 25, M = 5.92, SD = 0.91$ ) and designers ( $N = 26, M = 5.69, SD = 0.88$ );  $t(48) = 0.9062, p = 0.3693$ . The third question examined the students' perceptions of their ability to communicate. There was no significant difference found between the responses from engineers ( $N = 25, M = 5.92, SD = 1.08$ ) and designers ( $N = 26, M = 6.31, SD = 0.79$ );  $t(43) = 1.4622, p = 0.1510$ . The details of these results can be found in the following tables.

Table 3.1 Responses to Questions 1: Ideation

Group	Mean	Standard Deviation	N
Engineers	5.60	0.91	25
Designers	5.73	0.78	26

Table 3.2 Responses to Questions 2: Creativity

Group	Mean	Standard Deviation	N
Engineers	5.92	0.91	25
Designers	5.69	0.88	26

Table 3.3 Responses to Questions 3: Communication

Group	Mean	Standard Deviation	N
Engineers	5.92	1.08	25
Designers	6.31	0.79	26

The results of this statistical analysis provide some interesting insights about students' perceptions of the effects of the virtual environment. While both of these groups of students had notably different experiences, there were no statistical differences in their responses to the

questionnaire. This suggests that students see value in the use of LSICEs as a part of the design process, even with limited exposure. It also suggests that students with varying levels of experience recognize the benefits of this technology.

There is also valuable information that can be gained from the responses to these questions beyond of the statistical analysis. A summary of these responses can be found in figures 3.2, 3.3 and 3.4. By far, the most prominent feature of the composite responses is that none of the students provided a rating less than 4 for any of the questions. This result suggests that, although some students may have felt the environment had no effect on their ideation, creativity, or communication, these abilities were not hindered.

Another important similarity between these two groups is in response to the first and second questions regarding the impact of the environment on their ideation and creativity. In both groups, the largest percentage of students responded with a 6 to these questions. This seems to suggest that both groups felt that the LSICE improved their ability to ideate and improved their creativity. That being said, of all three questions, communication has the greatest number of students rating it as a 6 or higher in both groups, suggesting that both groups found communication to be the ability that was most aided by the virtual environment.

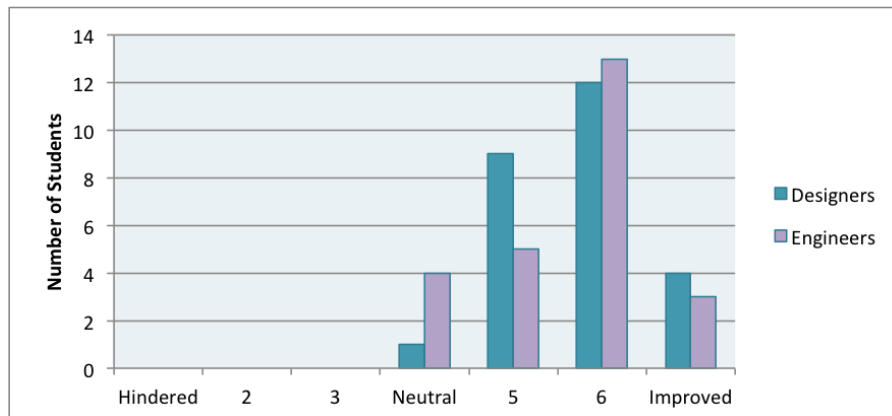


Figure 3.2 Responses to Questions 1: Ideation

These findings suggest that while the majority of students from both groups felt that the virtual environment improved ideation, creativity and communication, there were some important differences in which areas each group found the LSICE to be the most helpful. For

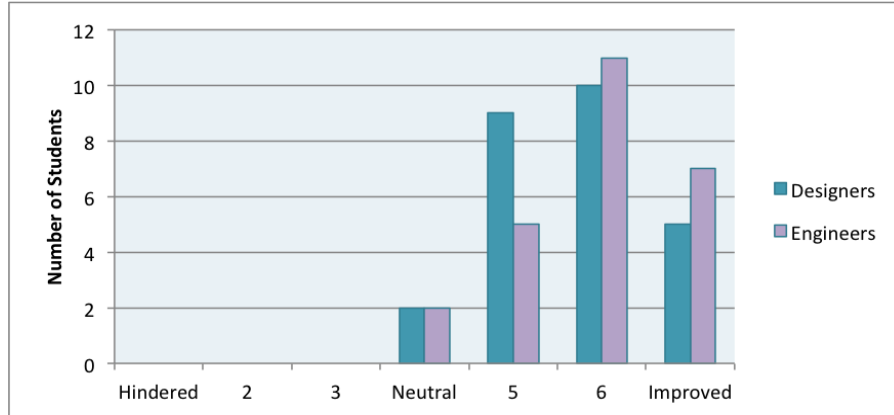


Figure 3.3 Responses to Questions 2: Creativity

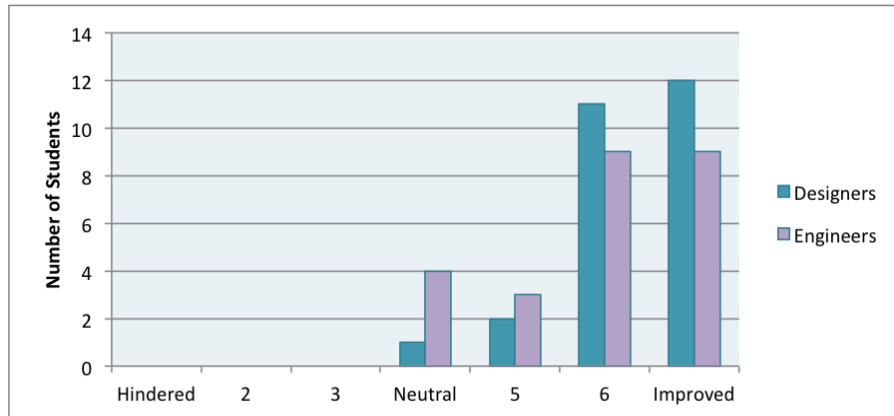


Figure 3.4 Responses to Questions 3: Communication

instance, creativity received the highest percentage of student ratings of 6 or higher from the engineering students; however within the group of design students, communication received the highest percentage of student rankings of 6 or higher. This suggests that while the engineering students found the environment most helpful in improving their creativity, the design students found that communication was most aided by the use of METaL. This could be due to the differences in educational styles of these two disciplines. Design education tends to center on ideation and creativity rather than communication. Engineering education does not have a significant focus in these topics. It is likely that the students felt the greatest help from the environment in the aspects of their professional toolboxes that were the most lacking.

### 3.3.2 Short answer responses

Much like the responses to the first set of questions, there were some similarities and differences in the students' responses to the open-ended questions. The data that were collected from these questions provide some interesting insights into the research questions. There were three common themes that emerged among both of these groups of students.

#### 3.3.2.1 Effects of full-scale visualization using LSICEs

One of the key features of LSICEs is that they allow the users to view virtual models in one-to-one size, or full scale. This element was the primary benefit noted by both groups of students. Many of the students made comments regarding the opportunities provided by METaL in allowing them to view their designs in this manner.

“It was very helpful to be able to view the projects at full-scale. By viewing them at full-scale, you could determine if elements of the design were sized correctly or if they needed to be altered.” -Design Student

Some of the comments made by the students illustrate that their ability to view their models in a life-size scale provided them with the unique opportunity to see their designs as they had designed them before beginning the time-consuming prototype phase. In some cases, viewing 3D models allowed students to catch mistakes prior to the prototyping process.

“It was really cool. I only noticed so many things from SolidWorks. We realized that a few crucial parts were oriented incorrectly. This was helpful.” -Engineering Student

As is highlighted by this comment in particular, seeing the designs in full-scale allows students to determine if the models need to be altered without having to waste time and materials late in the design phase. This technology is particularly useful in design education. Oftentimes, the material costs necessary to allow all of the students to explore the prototyping phase can be prohibitively expensive. However, this phase is a crucial part of education as students are

learning about spatial relationships, manufacture-ability of designs and interactions of mechanisms. Other students highlighted benefits related to viewing their full-scale models in METaL with comments such as

“Being able to use this technology is an advantage to designers in that they can see their designs in a real scale. This can be especially important with communication between designers and clients, as well as other contributors.” -Design Student

and

“The life-size rendering. It gives you more accurate feel than you would through the screen on a computer. It helped make alterations because sometimes what you thought was a good size for a component was in reality too big or vice versa. Sometimes you tend to lose track of scale in relation to your object and this helps a lot.” -Engineering Student

This emphasizes that the experiences held by individual students were not unique. Overall the majority of the students recognize the benefits of being able to see their designs in full-scale prior to creating prototypes.

### **3.3.2.2 Effects of interaction methods**

The ability to interact with 3D models in a more natural manner also has many benefits for students. Mice have become the main method for interaction in nearly all computer systems today. Newer generations of students can hardly remember the days before keyboards existed. As such, they have learned to adapt their methods of interaction to accommodate these devices. For composing a word document or browsing the Internet, they work just fine. They are not, however, intuitive to use for exploring 3D geometry. When a user interacts with a physical object, they use their hands to pick it up and examine it, rather than selecting a single point in which to rotate the object around. The lack of intuitive interaction with 3D objects makes viewing these objects in their full capacities quite challenging. However, the use of the wand and position tracking within the virtual space allows students to manipulate objects in a more natural manner. This was an observation that was articulated by various students:

“It is a whole new experience to be able to just look around a certain object rather than rotating it on the screen. I think because it is more intuitive to human nature, this system and others like it will be very successful in the future.” -Design Student  
and

“My favorite aspect of using METaL was being able to 'experience' our design and interact with it before fabricating it. I enjoyed the control over the design and the freedom to move parts around the environment to see how the parts are integrated in the design.” -Engineering Student

The ability to closely examine a 3D model is a critical part of the design process. By visualizing these designs in a full-scale environment with natural interaction methods, potential challenges in the design become much more visible, allowing students to make key design changes before the prototyping process begins. This improved ability to interact with models in the virtual environment also has a significant effect on students' abilities to communicate and collaborate in the virtual environment.

### **3.3.2.3 Effects of LSICES on communication and collaboration**

The use of LSICES in minimizing the costs associated with design changes late in the process is a well-known feature of various virtual reality technologies. A less commonly known benefit of these environments; however, is their use in facilitating communication and collaboration. The benefit of LSICES in improving communication was clearly highlighted in the student's responses to the first questions, however many students also emphasized this point in their comments:

“My favorite aspect is how it bridges the gap from design intent to representation and communication. One large issue I see brought up again and again in design is the limited ways to communicate the intention and design to the viewer. The METaL lab allows a representation style unlike anything before.” -Design Student

and

“METaL is fantastic for allowing other designers and/or clients to understand aspects of a design they could not gather from oral or 2D representations. It is great to have the vision, which was once restricted to your imagination alone, presented so completely.” -Design Student

The communication benefits of the LSICEs seem to be acknowledged more by the design students than by the engineering students, a feature of the data that also came through in the analysis of the first questions. However, this illustrates the potential that this technology has eliminate communication barriers between disciplines.

### **3.3.3 Limitations of the LSICE**

While the data suggests that the students overwhelmingly found METaL to be a useful tool in many parts of the design process, there were a few shortcomings that were highlighted. One of the primary limitations concerned manipulation and interaction within the environment. While the wand provides more natural interaction in the environment, the act of manipulating objects in 3D space also comes with its own challenges. Many of the students mentioned a desire to reach out and grab the objects with their hands to rotate and move the models. Unfortunately, while digital gloves do have their advantages, many of them are tethered by wires to a computer, making it difficult to move around a large virtual environment. While gesture based interactions are becoming increasingly more prevalent, the technology has not yet developed to a point where it is reliable in larger, multidimensional spaces. All of these technologies do however show great promise for the future of Immersive Computing Technology (ICT).



Another point that was brought up by a few students was related to certain textures that were unable to be rendered in the environment. One of the biggest challenges that researchers face involves compatibility with existing technologies. As one software package is updated, others take time to follow, which can lead to a loss in some minor functionalities. A robust software package that streamlines the conversion of CAD models into models that can be rendered into a virtual environment is in high demand. This capability would drastically minimize the learning curve of working with ICT and make the technology much more accessible to students of all backgrounds and skill levels. Additionally, many of the engineering students emphasized a desire to animate motion of their models and collision detection so that components could be assembled more realistically. This is a capability with many current softwares, however, when rendering items in a virtual environment, there are limits to the processing capabilities of the hardware. However, regular advancements in this technology, the days are near when this will no longer be concern.

### **3.3.4 Conclusions**

While there is still room for advancements in this technology, this research shows that LSICEs hold great promise for engineering and design students. As this new generation of students enters the classroom, technology will play a key role in engaging them and teaching them the fundamental tools that are necessary for today's professionals. These tools have the potential as an effective means by which to provide students with key skills related to communicating and collaborating with their peers.

## CHAPTER 4 INVESTIGATING THE IMPACT OF LARGE-SCALE IMMERSIVE COMPUTING ENVIRONMENTS ON COLLABORATION BETWEEN DESIGNERS AND ENGINEERS

Interdisciplinary collaboration is more important than ever before. While many researchers have explored methods for engaging students in collaborative learning, cross-disciplinary collaboration has not been studied extensively. The complexity of the challenges that our society faces today are more interdisciplinary than ever before. This study seeks to understand how the use of LSICEs lead to improved perceptions of communication, visualization and sense of presence which have the potential to lead to more effective interdisciplinary collaboration.

### 4.1 Research questions

The benefits of LSICEs are numerous. Among these benefits is the opportunity to facilitate collaboration between disciplines. While the overarching goal of this research is to understand how LSICEs can be used to improve the design thinking and decision making skills of engineering and design students, this study was motivated by the primary research questions:

1. Does the LSICE improve the students' perceived ability to communicate with a team?
2. Do the students feel a sense of presence in the virtual environment?
3. Does the LSICE improve the student's perceived ability to visualize designs?

The results of this research will provide increased understanding of the role that LSICEs play in the design process and how these tools affect interdisciplinary collaboration between engineering and design students. We also hope to learn more about some of the challenges students face in using this unique environment in an effort to improve the future experiences of students.

## 4.2 Methods

This study seeks to evaluate the perceptions of the use of LSICEs by engineering and design students as they worked together on a collaborative design task. In this study, teams of four, consisting of two engineers and two designers, worked together to complete a design review of a common household appliance using a LSICE called the Multi-modal Experimental Testbed and Laboratory (METaL).

### 4.2.1 Participants

A total of 20 students were recruited to participate in this research study. There were 10 engineering students and 10 design students; 10 males and 10 females; 10 were undergraduates and 10 were graduate students. The average age of the participants was 22.7. Participants had between one and five years of previous experience within their given discipline, with an average of 2.7. The majority of research subjects had little to no experience with virtual reality; however, four respondents indicated a moderate amount of exposure to the technology. Students worked in teams of four to complete the design review.

### 4.2.2 Software and hardware

The METaL was used to provide students with the opportunity to visualize and evaluate their designs. The METaL virtual environment consists of two walls and a floor. Three Digital Projection International TiTAN WUXGA-3D projectors display images on each of the walls of the system. An ART Track Pack 4 infrared optical tracking system is used to track the head and wand positions of a single user. Students were able to navigate around the environment and interact with objects in the scene using a wand with infrared markers attached.

A VR Juggler-based (Bierbaum et al., 2001) application called VRJuggLua (Pavlik and Vance, 2012) was used to render the environment in which the students interacted. This software brings together the capabilities of VR-Juggler with the open source graphics toolkit, Open Scene Graph (OSG) and the simple yet effective scripting language, Lua. Using this software, a variety of display and input devices can easily be added to an immersive VR



Figure 4.1 Virtual Kitchen Environment

application, allowing a user to manipulate and interact with 3D models within a scene.

Students were able to interact with the blender using a Nintendo Wiimote wand. Individual parts could be selected by cycling through each part with the left and right arrow keys of the wand. Selected parts were then able to be moved freely throughout the environment using the position-tracked Wiimote wand without colliding with other parts or models within the rest of the scene. Individual parts could also be reset to their original position.

#### 4.2.3 Procedure

Students participated in this study in groups of four. Each group consisted of two design students and two engineering students. Participants were first given an introductory survey to gather information about their backgrounds and previous experiences with virtual reality technology. After a brief introduction to the environment, each group was asked to work together to conduct a design review of a virtual model of a blender within a kitchen scene as can be seen in figure 4.2. This involved discussing their perceived benefits and drawbacks of the functional, aesthetic and ergonomic qualities of the design. After 25 minutes in the virtual environment, students were asked to work as a team to compile a document summarizing their



Figure 4.2 Participants Interacting in Virtual Environment

design review. Teams were given the liberty to structure the summary however they saw fit. The primary purpose of the written summary was to gain an understanding of how well the students translated the discussion in the virtual environment to a physical artifact. Both the discussions during the design review and the team writing time was recorded. Finally students were asked to complete an exit survey about their experiences in the virtual environment.

### 4.3 Results

After each design review, the students were asked to fill out a brief survey consisting of three parts. The first part of the survey contained three five-point Likert scale questions. They were asked to rate their impressions of the effect of the immersive environment on:

1. their ability to interact in the environment
2. the visualization of the design
3. their ability to communicate with their peers

Student responses can be found in 4.3. Participants responded positively to all three questions. Responses to the ability to interact in the environment received the lowest score by the majority of the students; however, most felt that the virtual environment *somewhat improved* their

ability to interact with the virtual model. The majority of participants felt that the virtual environment improved their ability to communicate with their peers. This question received the highest score by the greatest number of participants of the three questions that they were given. Many students also responded to the question about their ability to visualize their designs in the virtual environment positively as well. Although there were not as many students that felt the environment improved their ability to visualize the design, half of the students still rated visualization a five.

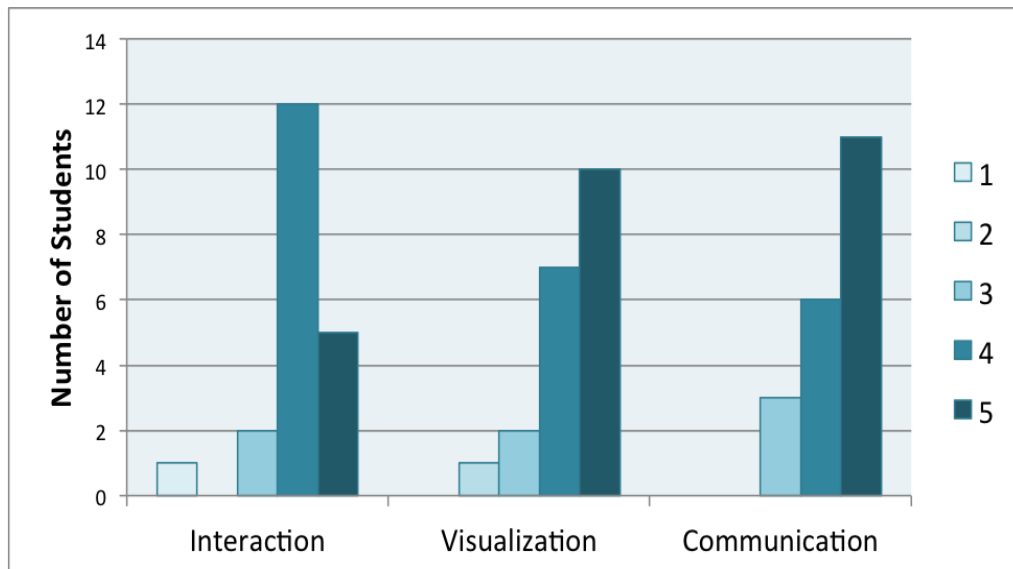


Figure 4.3 Responses to Likert Survey Questions

In addition to the three questions, participants were also given a series of open-ended, short-answer questions to learn what aspects of the LSICE they felt were beneficial and what improvements needed to be made. There were a few key themes that emerged from the responses of the participants. This included discussion of the benefits of METaL in facilitating communication, creating an immersive experience, and providing effective visualization of designs. Many of the shortcomings of the environment that the students identified were related to the graphics in the scene. Several students mentioned a desire for higher resolution while others reported a need for better lighting of the environment.

Finally, a subset of the Witmer presence questionnaire (Witmer and Singer, 1998) was administered to get a sense of their level of immersion in the virtual environment. Based

on this questionnaire, students felt that the LSICE was most effective in using visual cues to involve users in the environment and providing a compelling sense of moving around and objects moving through space. Students were less decided on the effectiveness of the environment in engaging all of their senses. They primarily felt the environment failed to use auditory cues to engage them. As there was no audio provided in this scene, this is a logical finding.

## 4.4 Discussion

This data reveals some interesting insights related to the stated research questions:

1. Does the LSICE improve the students' perceived ability to communicate with a team?
2. Do the students feel a sense of presence in the virtual environment?
3. Does the LSICE improve the student's perceived ability to visualize designs?

### 4.4.1 Effects of the LSICE on communication with teams

Regarding the students' perceptions of the effect of the virtual environment on their ability to communicate, survey results seem to indicate that the students believe the LSICE has a positive effect on their ability to communicate. In response to the initial questions, 17 of the 20 participants indicated that they believed the virtual environment at least somewhat improved their ability to communicate with their team members. One comment that was provided in response to the short answer questions particularly emphasized this point.

"I liked that we all had to figure it out together and we were all looking at the same thing. I felt that everyone was very present and engaged, which is different from a typical design critique." -Design Student

The comments from this student really capture the potential capabilities of LSICE, to engage students in a manner that previous methods have not. There are several conceivable explanations for this improved sense of engagement. The current generation of students is accustomed

to constantly being connected to technology through cell phones and laptops in the classroom. When they are brought into an environment where those distractions are removed, they are free to engage more effectively with their peers.

Additionally, the LSICE also creates an atmosphere in which all members of the team are on a level playing ground. The novelty of the technology provides an environment in which no single member is more knowledgeable than any other. This helps to eliminate barriers that are created by disconnects in expertise. LSICEs also provide a unique sense of presence that is not mimicked by other visualization methods, further improving their abilities to perform a given task.

#### **4.4.2 Perceptions of presence in LSICEs**

The students' perceptions of their sense of presence in the virtual environment were conveyed throughout their survey responses. There were several comments from students that highlighted their impressions of presence in the virtual environment. For instance,

“When walking around, it adjusted to the perspective of the user. The 3D was very smooth and became very immersive after a short period of time.” -Design Student  
and

“Being immersed in the environment was pretty darn awesome. It was cool to have ‘Jedi force powers’ in that you could lift items and look at them in the air.”  
-Engineering Student

The Witmer Presence Questionnaire also shows positive results regarding the students' sense of presence in the environment. Over 60 percent of participants felt that they could manipulate objects, closely examine objects, and examine objects from multiple viewpoints very well in the immersive environment. All of the participants reported feeling immersed by some aspect of the virtual environment. Research has consistently shown that a sense of presence leads to improved task performance (Witmer and Singer, 1998). The nature of this team environment provided the students with the opportunity to take on roles in which they were most immersed in the environment.



#### 4.4.3 Effects of the LSICE on visualization of 3D geometry

Sense of presence in conjunction with the ability to interact in a virtual environment both play a key role in the effect of LSICEs on visualization of 3D geometry. Within the virtual environment, students were able to evaluate several features of the design without having to think about how to interact with it.

“The scene was really neat and interactive; you could walk around the kitchen with the mixer and ”pour” into the glasses or bowls or put the mixer in the sink.”

-Engineering Student

and

“I like that when the primary user walked forward it zoomed in rather than using the remote, I actually felt like I was in the kitchen and as if I could hold the object.”

-Design Student

These quotes highlight the capabilities of the LSICE to visualize features of a design within a given context, improving their ability to conduct a comprehensive design review. Students also commented on the ability to dissect the product and evaluate individual components of the design:

“You could manipulate the different features to different angles. A lot of times even in engineering drawings there are 3 views. Here, there are infinite.” -Engineering Student

and

“It allowed you to look at every angle of the product as well as allowing you to disassemble pieces and look at them separately.” -Engineering Student

There were several pieces of information that reflect a positive outcome with regards to the students’ perceived ability to visualize designs. Student responses to the initial portion of the survey also provided an added insight into some of the specific benefits of LSICEs provided

by visualizing 3D geometry in the virtual environment. In response to the initial questions concerning the visualization of designs, 85 percent of participants indicated that they felt the LSICE improved their abilities to some extent.

#### **4.4.4 Limitations of the LSICE**

Along with favorite features of the virtual environment, participants were also asked to provide feedback on the features that they felt needed improvement. These responses could largely be separated into two groups, graphics and interaction. Many students expressed a desire for higher resolution and more detail of the system.

“More detail would be ideal. The graphics were good, but I feel that a higher level of detail would allow for a better critique.” -Design Student

Other students mentioned the need for improvements in lighting within the environment. One of the benefits of LSICEs is that participants can walk around the environment as they would in a physical space. However, because the system tracks the position for only one user, the views can become distorted for others in the space. Higher resolution projectors are available, but cost is a limiting factor.

Some of the other feedback provided by participants indicated challenges in manipulating parts within the environment. While interaction in the virtual environment allows users to move around the space in a more natural manner, interacting with objects in a space is a subject of continual research. There are many methods that have been employed in various capacities. Gloves have been used in some virtual environments, however most gloves are tethered to computers by wires or have limited ranges, making them challenging to use in such a large virtual environment. Wands are becoming an increasingly common solution to interaction in large 3D environments. However, mapping buttons to specific commands presents its own challenges. As these tools are relatively new, a convention has not yet been established, meaning that users are required learn new mappings in each unique application. As this technology becomes more prevalent and conventions are widely established, users will become more familiar with interactions in the environment.

## 4.5 Conclusions and future work

Overall LSICEs show promise as an effective means of facilitating collaboration between disciplines that have different skill sets. Students perceive these virtual environments to be effective in facilitating collaboration between members of various disciplines. Creating an environment that motivates students to collaborate across disciplines has the potential not only to improve their ability to communicate, but also to improve the frequency in which they reach out to members of other disciplines, helping to combat the silo effect that is prevalent in the current educational landscape.

There is still sizable research that needs to be conducted in order to gain an understanding of the quantitative performance impact of this technology within a classroom context, however the perceived benefits of this tool by the students utilizing it has value in itself. It is also important to gather information about how this tool can be used to facilitate collaboration between disciplines outside of design and engineering in order to gain more insights as to how this technology can be applied in a broader educational setting.

## CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

The overarching goal of this research is to gain an understanding of how Large-Scale Immersive Computing Environments (LSICEs) can be used in an educational setting to improve communication and collaborations skills among designers and engineers. Two separate studies were conducted. In the first study, two classes, one engineering and one design, used the METaL virtual environment as a part of their class design projects. In the second, teams of engineers and designers came together to complete a design review task within the virtual environment.

The purpose of the first study was to gain an understanding of how students perceive the use of this technology when collaborating with their peers. Students found that the LSICE was a beneficial tool in their design process. Specifically they found the virtual environment to be useful in allowing them to see their designs in full scale, interact more naturally with their designs, and communicate with their peers.

The objective of the second study was to learn how this tool can be used to facilitate collaboration between disciplines. The findings of this study share many similarities with those of the previous study. Students felt the environment was particularly helpful in allowing them to visualize the design and interact naturally in the environment. However, students also reported an improved sense of presence and engagement in the environment.

LSICEs have the potential to improve Project-Based Learning (PBL) and engage students in new and unique ways. Student responses show many perceived benefits to LSICEs which have the potential to inspire student-driven interdisciplinary collaboration. The results from this research are quite promising; however, there is more research that is needed in order to learn more about the effects of LSICEs within the greater context of education as a whole.

## 5.2 Recommendations

The possibilities for the future of this work are numerous. As is often the case, once one question is answered, several more emerge. These studies evaluated the students' perceptions towards the technology; however, the students' perceptions towards members of opposite disciplines was not explored. This is one element that plays a particularly large role in the willingness of students to participate in interdisciplinary collaboration as well as the quality of the collaboration. The existing relationship between groups of students also plays a large part in how effectively they work together. By studying how LSICE are used differently by groups with established rapport as compared to newly formed groups, researchers can better understand how these environments can be employed most effectively.

Additionally, while the results of this research suggest that LSICEs can be an effective tool for engaging students in interdisciplinary collaboration, there is still much more research that must be conducted in order to validate the effectiveness of this tool in improving the performance of interdisciplinary teams. In order to gain a more definitive understanding of how this technology impacts classroom performance, a side-by-side comparative study within a classroom setting should be conducted.

More research is also needed to understand what types of tasks these environments are best suited for. By gaining information about the tasks that LSICEs are most effective with, researchers will also learn more about the specific educational contexts in which these tools can be most helpful. While this technology appears to be a beneficial for collaboration between engineers and designers, LSICEs also hold the potential to improve collaboration among and between a variety of other disciplines. In order to gain a better understanding of how these tools can be applied, additional investigation is needed.

When new technologies are introduced, there is often a sense of novelty that is associated with them. This novelty in itself can often affect how users interpret and interact with a tool. The novelty effect is not something that should be completely discarded. Often times new and innovative tools can be effective in bridging a divide that might not otherwise be crossed, opening up the opportunity for ideas that had not been previously considered. However, once

a technology becomes commonplace, this effect is often limited. Therefore it is important to understand what role novelty plays in the results of this research so that educators can learn what the best way to implement it is.

As this technology evolves, new opportunities for Immersive Computing Technologies abound. As advancements increase the accessibility of these tools, new applications will be uncovered, leading to opportunities never before considered. Within education alone the research possibilities are numerous and each new study begets another set of research questions. The future of this research is as boundless as the technology itself.

## APPENDIX A SURVEY FOR DESIGN EDUCATION STUDY

Please rate your impressions of the immersive environment on your design process on the scales below.

---

Hindered Ideation	1	2	3	4	5	6	7	Improved Ideation
_____		_____		_____		_____		_____

Hindered Creativity	1	2	3	4	5	6	7	Improved Creativity
_____		_____		_____		_____		_____

Hindered Communication	1	2	3	4	5	6	7	Improved Communication
_____		_____		_____		_____		_____

---

What would you improve about the system if you could?

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What was your favorite aspect of being able to use METaL to view your designs?

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Do you have any other questions or comments related to the use of METaL?

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**APPENDIX B SURVEYS FOR COLLABORATIVE STUDY****Pre-Survey**

What is your current program of study?

- Engineering
- Design
- Other \_\_\_\_\_

What is your area of focus?

- Mechanical Engineering
- Computer Engineering
- Industrial Engineering
- Materials Engineering
- Aerospace Engineering
- Agricultural Engineering
- Construction Engineering
- Civil Engineering
- Software Engineering
- Other \_\_\_\_\_

What is your area of focus?

- Architecture
- Planning
- Graphic Design
- Industrial Design
- Interior Design
- Integrated Studio Arts
- Landscape Architecture
- Other \_\_\_\_\_



Please briefly describe your design experience.

How much experience do you have utilizing Computer Aided Drafting (CAD) Software?

None |      | significant

How much experience with virtual reality do you have?

None |      | Significant

What is your age?

What is your gender?

- Male
- Female
- Prefer not to disclose

## Post-Survey

Please rate your impressions of the effect of the immersive environment on the following aspects of your review process on the scales below.

	Hindered	Somewhat Hindered	Neutral	Somewhat Improved	Improved
Ability to Interact in the Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Visualization of your Design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ability to Communicate with your Peers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

What improvements would you make to the *system* if you could?

What improvements would you make to the *interaction* within the environment if you could?

What were your favorite features of the METaL virtual environment?

What were the biggest drawbacks to using the virtual environment?



**APPENDIX C IRB APPROVAL FORMS**

**Date:** 5/3/2013

**To:** Meisha Rosenberg  
1620 Howe Hall

**CC:** Dr. Judy Vance  
1620 Howe Hall

**From:** Office for Responsible Research

**Title:** Use of Immersive Environments in Design Education

**IRB ID:** 13-192

**Study Review Date:** 5/2/2013

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

**Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form.** A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. **Only the IRB or designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

Please be aware that **approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or [IRB@iastate.edu](mailto:IRB@iastate.edu).

**INSTITUTIONAL REVIEW BOARD (IRB)**

**Exempt Study Review Form**

RECEIVED  
08  
APR 05 2013

Title of Project: Use of Immersive Environments in Design Education By IRB

Principal Investigator (PI): <b>Meisha Rosenberg</b>		Degrees: B.S.
University ID: <b>579117539</b>	Phone: (515) 633-7728	Email Address: meishar@iastate.edu
Correspondence Address: 1620 Howe Hall Iowa State University Ames IA 50010		
Department: Mechanical Engineering		College/Center/Institute: Engineering
PI Level: <input type="checkbox"/> Tenured, Tenure-Eligible, & NTER Faculty <input type="checkbox"/> Adjunct/Affiliate Faculty <input type="checkbox"/> Collaborator Faculty <input type="checkbox"/> Emeritus Faculty <input type="checkbox"/> Visiting Faculty/Scientist <input type="checkbox"/> Senior Lecturer/Clinician <input type="checkbox"/> Lecturer/Clinician, w/Ph.D. or DVM <input type="checkbox"/> P&S Employee, P37 & above <input type="checkbox"/> Extension to Families/Youth Specialist <input type="checkbox"/> Field Specialist III <input type="checkbox"/> Postdoctoral Associate <input checked="" type="checkbox"/> Graduate/Undergrad Student <input type="checkbox"/> Other (specify: )		

<b>FOR STUDENT PROJECTS</b> (Required when the principal investigator is a student)		
Name of Major Professor/Supervising Faculty: Dr. Judy Vance		
University ID: 608036168	Phone: (515) 294-9474	Email Address: jmvance@iastate.edu
Campus Address: 1620 Howe Hall		Department: Mechanical Engineering
Type of Project: (check all that apply) <input checked="" type="checkbox"/> Thesis/Dissertation <input type="checkbox"/> Class Project <input type="checkbox"/> Other (specify: )		

Alternate Contact Person:	Email Address:
Correspondence Address:	Phone:

**ASSURANCE**

- I certify that the information provided in this application is complete and accurate and consistent with any proposal(s) submitted to external funding agencies. Misrepresentation of the research described in this or any other IRB application may constitute non-compliance with federal regulations and/or academic misconduct.
- I agree to provide proper surveillance of this project to ensure that the rights and welfare of the human subjects are protected. I will report any problems to the IRB. See [Reporting Adverse Events and Unanticipated Problems](#) for details.
- I agree that modifications to the approved project will not take place without prior review and approval by the IRB.
- I agree that the research will not take place without the receipt of permission from any cooperating institutions, when applicable.
- I agree to obtain approval from other appropriate committees as needed for this project, such as the IACUC (if the research includes animals), the IBC (if the research involves biohazards), the Radiation Safety Committee (if the research involves x-rays or other radiation producing devices or procedures), etc.
- I understand that approval of this project does not grant access to any facilities, materials or data on which this research may depend. Such access must be granted by the unit with the relevant custodial authority.
- I agree that all activities will be performed in accordance with all applicable federal, state, local, and Iowa State University policies.

Signature of Principal Investigator \_\_\_\_\_ Date \_\_\_\_\_

Signature of Major Professor/Supervising Faculty \_\_\_\_\_ Date \_\_\_\_\_  
 (Required when the principal investigator is a student)

- I have reviewed this application and determined that departmental requirements are met, the investigator(s) has/have adequate resources to conduct the research, and the research design is scientifically sound and has scientific merit.

Signature of Department Chair \_\_\_\_\_ Date \_\_\_\_\_

<b>For IRB Use Only</b>	<input type="checkbox"/> Not Research Per Federal Regulations	<input type="checkbox"/> No Human Participants	Review Date: May 2, 2013
	<input checked="" type="checkbox"/> Minimal Risk	EXEMPT Per 45 CFR 46.101(b): 2	
IRB Reviewer's Signature			

**Date:** 4/25/2014

**To:** Meisha Rosenberg  
1620 Howe Hall

**CC:** Dr. Judy Vance  
1620 Howe Hall

**From:** Office for Responsible Research

**Title:** Investigating the Impacts of Large-Scale Immersive Computing Environments on Engineering Design Education

**IRB ID:** 14-252

**Study Review Date:** 4/25/2014

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

**Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form.** A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. **Only the IRB or designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

Please be aware that **approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**



Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or [IRB@iastate.edu](mailto:IRB@iastate.edu).

**INSTITUTIONAL REVIEW BOARD (IRB)  
Exempt Study Review Form**

IRB ID: 14-252  
RECEIVED  
APR 10 11 10 2014  
By IRB

Title of Project: Investigating the Impacts of Large-Scale Immersive Computing Environments on Engineering Design Education

Principal Investigator (PI): <b>Meisha Rosenberg</b>		Degrees: BS:Mechanical Engineering
University ID: <b>579117539</b>	Phone: 515-633-7728	Email Address: meishar@iastate.edu
Correspondence Address: 1620 Howe Hall, Ames, IA 50011		
Department: Mechanical Engineering		College/Center/Institute: Virtual Reality Applications Center
PI Level: <input type="checkbox"/> Tenured, Tenure-Eligible, & NTER Faculty <input type="checkbox"/> Adjunct/Affiliate Faculty <input type="checkbox"/> Collaborator Faculty <input type="checkbox"/> Emeritus Faculty <input type="checkbox"/> Visiting Faculty/Scientist <input type="checkbox"/> Senior Lecturer/Clinician <input type="checkbox"/> Lecturer/Clinician, w/Ph.D. or DVM <input type="checkbox"/> P&S Employee, P37 & above <input type="checkbox"/> Extension to Families/Youth Specialist <input type="checkbox"/> Field Specialist III <input type="checkbox"/> Postdoctoral Associate <input checked="" type="checkbox"/> Graduate/Undergrad Student <input type="checkbox"/> Other (specify: )		


**FOR STUDENT PROJECTS** (Required when the principal investigator is a student)


Name of Major Professor/Supervising Faculty: Dr. Judy M. Vance		
University ID: <b>608036168</b>	Phone: 515-294-9474	Email Address: jmvance@iastate.edu
Campus Address: 1620 Howe Hall, Ames, IA 50011		Department:
Type of Project: (check all that apply) <input checked="" type="checkbox"/> Thesis/Dissertation <input type="checkbox"/> Class Project <input type="checkbox"/> Other (specify: )		

Alternate Contact Person:	Email Address:
Correspondence Address:	Phone:


**ASSURANCE**

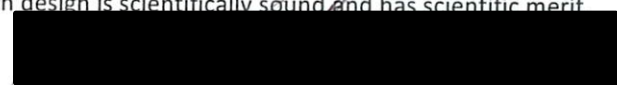
- I certify that the information provided in this application is complete and accurate and consistent with any proposal(s) submitted to external funding agencies. Misrepresentation of the research described in this or any other IRB application may constitute non-compliance with federal regulations and/or academic misconduct.
- I agree to provide proper surveillance of this project to ensure that the rights and welfare of the human subjects are protected. I will report any problems to the IRB. See [Reporting Adverse Events and Unanticipated Problems](#) for details.
- I agree that modifications to the approved project will not take place without prior review and approval by the IRB.
- I agree that the research will not take place without the receipt of permission from any cooperating institutions when applicable.
- I agree to obtain approval from other appropriate committees as needed for this project, such as the IACUC (if the research includes animals), the IBC (if the research involves biohazards), the Radiation Safety Committee (if the research involves x-rays or other radiation producing devices or procedures), etc., and to obtain background checks for staff when necessary.
- I understand that IRB approval of this project does not grant access to any facilities, materials, or data on which this research may depend. Such access must be granted by the unit with the relevant custodial authority.
- I agree that all activities will be performed in accordance with all applicable federal, state, local, and Iowa State University policies.


  
Signature of Principal Investigator \_\_\_\_\_ Date \_\_\_\_\_

  
Signature of Major Professor/Supervising Faculty \_\_\_\_\_ Date \_\_\_\_\_  
(Required when the principal investigator is a student)

- I have reviewed this application and determined that departmental requirements are met, the investigator(s) has/have adequate resources to conduct the research, and the research design is scientifically sound and has scientific merit.

  
Printed Name of Department Chair/Head/Director \_\_\_\_\_

  
Signature of Department Chair/Head/Director \_\_\_\_\_ Date \_\_\_\_\_

For IRB Use Only	<input type="checkbox"/> Not Research Per Federal Regulations	<input type="checkbox"/> No Human Participants	Review Date: 4/25/2014
	<input checked="" type="checkbox"/> Minimal Risk	EXEMPT Per 45 CFR 46.101(b): 2	
IRB Reviewer's Signature 		April 25, 2014	

IOWA STATE UNIVERSITY  
OF SCIENCE AND TECHNOLOGY

Institutional Review Board  
Office for Responsible Research  
Vice President for Research  
1138 Pearson Hall  
Ames, Iowa 50011-2207  
515 294-4566  
FAX 515 294-4267

**Date:** 12/15/2014

**To:** Meisha (Rosenberg) Berg  
1620 Howe Hall

**CC:** Dr. Judy Vance  
1620 Howe Hall

**From:** Office for Responsible Research

**Title:** Investigating the Use of Virtual Reality in Collaborative Design Tasks Between Engineers and Designers

**IRB ID:** 14-552

**Approval Date:** 12/15/2014      **Date for Continuing Review:** 12/14/2016

**Submission Type:** New      **Review Type:** Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, including the recruitment materials and informed consent documents that have the IRB approval stamp.
- **Retain signed informed consent documents for 3 years after the close of the study**, when documented consent is required.
- **Obtain IRB approval prior to implementing any changes** to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- **Immediately inform the IRB of (1) all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.
- **Stop all research activity if IRB approval lapses**, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 1138 Pearson Hall, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or [IRB@iastate.edu](mailto:IRB@iastate.edu).

## INSTITUTIONAL REVIEW BOARD (IRB) Application for Approval of Research Involving Humans

Collaborative (b)

Title of Project: Investigating the Use of Virtual Reality in Collaborative Design Tasks Between Engineers and Designers

Principal Investigator (PI): Meisha Rosenberg Berg <i>per PI request 10/20/14</i>		Degrees: B.S. Mechanical Engineering
University ID: 579117539	Phone: 515-633-7728	Email Address: meishar@iastate.edu
Correspondence Address: 1620 Howe Hall Ames IA, 50011		
Department: Mechanical Engineering		College/Center/Institute: Virtual Reality Applications Center
PI Level: <input type="checkbox"/> Tenured, Tenure-Eligible, & NTER Faculty <input type="checkbox"/> Adjunct/Affiliate Faculty <input type="checkbox"/> Collaborator Faculty <input type="checkbox"/> Emeritus Faculty <input type="checkbox"/> Visiting Faculty/Scientist <input type="checkbox"/> Senior Lecturer/Clinician <input type="checkbox"/> Lecturer/Clinician, w/Ph.D. or DVM <input type="checkbox"/> P&S Employee, P37 & above <input type="checkbox"/> Extension to Families/Youth Specialist <input type="checkbox"/> Field Specialist III <input type="checkbox"/> Postdoctoral Associate <input checked="" type="checkbox"/> Graduate/Undergrad Student <input type="checkbox"/> Other (specify: )		

**FOR STUDENT PROJECTS** (Required when the principal investigator is a student)

Name of Major Professor/Supervising Faculty: Dr. Judy M. Vance		
University ID:	Phone: 515-294-9474	Email Address: jmvance@iastate.edu
Campus Address: 2644 Howe Hall Ames, IA 50011		Department: Mechanical Engineering
Type of Project (check all that apply): <input type="checkbox"/> Thesis/Dissertation <input type="checkbox"/> Class Project <input checked="" type="checkbox"/> Other (specify: Research Study)		

Alternate Contact Person:	Email Address:
Correspondence Address:	Phone:

RECEIVED

OCT 20 2014  
By IRB

**ASSURANCE**

- I certify that the information provided in this application is complete and accurate and consistent with any proposals submitted to external funding agencies. Misrepresentation of the research described in this or any other IRB application may constitute non-compliance with federal regulations and/or academic misconduct.
- I agree to provide proper surveillance of this project to ensure that the rights and welfare of the human subjects are protected. I will report any problems to the IRB. See [Reporting Adverse Events and Unanticipated Problems](#) for details.
- I agree that modifications to the approved project will not take place without prior review and approval by the IRB.
- I agree that the research will not take place without the receipt of permission from any cooperating institutions when applicable.
- I agree to obtain approval from other appropriate committees as needed for this project, such as the IACUC (if the research includes animals), the IBC (if the research involves biohazards), the Radiation Safety Committee (if the research involves x-rays or other radiation producing devices or procedures), etc., and to obtain background checks for staff when necessary.
- I understand that IRB approval of this project does not grant access to any facilities, materials, or data on which this research may depend. Such access must be granted by the unit with the relevant custodial authority.
- I agree that all activities will be performed in accordance with all applicable federal, state, local, and Iowa State University policies.

\_\_\_\_\_  
Signature of Principal Investigator      Date

\_\_\_\_\_  
Signature of Major Professor/Supervising Faculty      Date  
(Required when the principal investigator is a student)

- I have reviewed this application and determined that departmental requirements are met, the investigator(s) has/have adequate resources to conduct the research, and the research design is scientifically sound and has scientific merit.

\_\_\_\_\_  
Printed Name of Department Chair/Head/Director

\_\_\_\_\_  
Signature of Department Chair/Head/Director      Date

For IRB Use Only  Approval Not Required: <input type="checkbox"/>  Not Research: <input type="checkbox"/>  No Human Subjects: <input type="checkbox"/>	Full Committee Review: <input type="checkbox"/> EXPEDITED per 45 CFR 46.110(b): <u>1</u> Category <u>6,7</u> Letter	Review Date: <u>December 15, 2014</u> Approval/Determination Date: <u>December 15, 2014</u> Approval Expiration Date: <u>December 19, 2014</u>
	Not Approved: <input type="checkbox"/>	Risk: Minimal <input checked="" type="checkbox"/> More than Minimal <input type="checkbox"/>
	IRB Reviewer's Signature: _____ <span style="float: right; color: blue;">2014</span>	

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