Learning Building Sciences in Virtual Environments

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Abstract

This paper presents an interdisciplinary research project engaging students from Architecture, Construction, and Mechanical Engineering at Florida International University. The project builds on advances of recent technologies to develop, implement, and test a prototype immersive environment. The design of this environment aims to facilitate interdisciplinary education for design and construction of environmentally responsive buildings. The project integrates Augmented and Virtual Reality technologies with Building Information Modeling (BIM), visual simulations, and interactive lessons to create an effective and interactive environment for learning. The paper examines how the use of these technologies in combination with collaborative learning approaches impact student motivation and attitudes towards further engagement in collaborative learning.

Introduction

The use and effectiveness of immersive environments for learning has been increasingly researched and examined. Current research shows that immersive environments such as Virtual Reality (VR) and Augmented Reality (AR) are among the most promising mediums to support learning. These technologies provide computer-generated simulations of the real or an imagined world that can serve as a rich and engaging context for learning [1]. Two features of these technologies, "immersion" and "interactivity", bring new dimensions to how people learn individually and collaboratively. Bryson describes immersion as the sense that the "user's point view or some parts of the user's body is contained within the computer generated-model" [2]. Immersion can be designed to facilitate experiential learning, where knowledge is produced through experience. Interactivity is another feature of these environments which can facilitate dynamic feedback, experimentation, and exploration [3]. Interacting with a responsive environment where the user can navigate and modify the learning context based on her own input is another capability that can be developed for educational proposes.

The following paper discusses a completed research project designed to leverage the capacity of immersive environments in support of interdisciplinary collaboration. The project integrates AR and VR with Building Information Modeling (BIM), visual simulations, and interactive lessons. Building on advances in our understanding of learning processes and educational theoretical perspectives, the project develops, implements, and tests two immersive prototype applications called "AR and VR Skope" to support collaboration among Architecture, Construction and Engineering (AEC) students. The project team includes faculty from Architecture, Construction, Mechanical Engineering and Computer Science.

Skope applications enable students at Florida International University's (FIU) to experience site visits of a campus building with augmented data and overplayed information. Through implementation and testing of these applications, the project aims to contribute to the ongoing research on the effectiveness of immersive environments, particularly as a scaffolding approach in support of interdisciplinary collaboration.

Interdisciplinary Collaboration

Interdisciplinary collaboration is becoming increasingly critical in a new era where complex problem-solving and innovative thinking require comprehension of a host of issues that go beyond disciplinary boarders. This is particularly true for building design and construction as AEC professionals are asked to collaborate in tackling the significant issues of the built environment.

Effective interdisciplinary collaboration, however requires interaction and exposure to different disciplinary perspectives early on in students' education. AEC professionals are often educated in knowledge silos bounded by disciplinary requirements, organizational structures, and in many cases dispersed locations. Knowledge silos impede an understanding of the broader issues and effective problem solving [4]. Without a concerted effort to utilize novel research and pedagogical approaches exposing students to activities, ideas, and methods across disciplinary boundaries, knowledge silos will continue to stand in the way of innovative thinking and discovery that lead to transformational solutions for critical problems.

Technological Advancement and Opportunities

Immersive technologies, simulation, data visualization, and easy-to-access geo-spatial datasets are creating new opportunities for educational interventions. Within this context, AR and VR environments promise to enhance face-to-face communication and support group interaction. The development of the Skope Applications is motivated by three advances in digital technologies.

First, there has been significant developments in Building Information Modeling (BIM). BIM is one of the most promising advances in the Architecture, Engineering and Construction industries [5]. BIM is a simulation comprised of a three-dimensional model of building project with links to all the required information connected with the project planning, design, construction or operation [6]. BIM models are the virtual equivalent of the actual building and can contain engineering data including structural, mechanical, electrical, and material metrics and quantities, as well as other information [7]. The possibility of exporting these models into fully immersive environment has opened numerous opportunities for the AEC community. Some integrated applications of AR and BIM models, are becoming prevalent in the construction industry.

Second is the increased processing speed and screen capability of hand-held devices. These advances are making AR and VR technologies user friendly and ubiquitous. Although head-mounted technologies provide a far superior immersive experience, cell phones and tablets are providing inexpensive alternatives. The possibility of adapting cell phones to VR and AR headsets by using easy to build cases made of cardboards and magnets, is making virtual reality walk-throughs, field trips, and site visits accessible to many.

Finally, there are concurrent leaps in developments of computer game engines with superior graphic capabilities. Game engines are software frameworks used for rendering, special data-structures, and techniques to visualize texture mapped 3D objects [8]. Game engines can incorporate physical realism, responsiveness, intelligence, and graphic user interface. They offer many advantages for creation of immersive environments. These include the possibility of working with off- the-shelf systems, access to documentation and source code, and customizable experience in a short time without expensive computer programming requirements [9].

The Skope applications leverage the advances of these technologies to create a realistic and immersive experience for learning about buildings. Through the integration of BIM and game engine technologies supported by handheld devices, the instrument provides for field investigation of a building, while offering location-sensitive information and supplemental on-demand lessons. Moreover, it aids students to gather critical information for solving interdisciplinary group projects.

The Theoretical Framework

AR and VR technologies offer immersion and interactivity. To examine if and how these features impact collaborative learning, design and development of the Skope Applications build on theoretical frameworks of Experiential Learning and Collaborative Problem solving.

Experiential Learning

Experiential Learning is a branch of the new science of learning that is based on Dewey's (1938) theory giving experience a central role in human learning and development. Dewey notes, "[E]ducation must be conceived as a continuing reconstruction of experience… the process and goal of education are one and the same thing" [10] . Kolb states that learning is best supported when students are engaged in a process that draws their beliefs and ideas about a topic so that they can be examined, tested, and integrated with new and more refined ideas [11]. Kolb describes learning as a four-stage process: concrete experience, reflective observation, abstract conceptualization and active experimentation. He contents that immediate experience is the basis for observation and reflection, which is assimilated to abstract concepts, where new ideas and actions can be generated [12].

The Skope applications leverage affordances of AR and VR technologies to support experiential learning. As students are enabled to participate in field visits either by physically being there or accessing the experience remotely, they can interact with various features of the instrument to learn about various aspects and systems of the building.

Collaborative Problem-Solving

Collaborative problem solving (CPS) is often based on a project-based approach where learning is organized around the investigation, explanation, and resolution of meaningful problem [13] . With this approach students learn through the experience of working through problems and learning centers on a complex situation or problem that does not have a single correct answer. Students work in collaborative groups to identify what they need to learn to solve a problem. They then apply their new knowledge to the problem. This works well with the three competencies associated with CPS: establishing and maintaining shared understanding, taking appropriate action, and establishing and maintaining team organization [14].

There are varying approaches to CPS depending on the context of the interactions. For some kinds of interactions, all members of the group will have similar knowledge and status whereas it is also possible to have variation between group members. The rules of engagement vary according to the learning context including; 1) collaborative work, writing, and design, 2) building consensus in decision making, 3) negotiations to foster win-win opportunities, and 4) argument and debates to gain better understanding of dilemmas [15].

The development of the Skope instrument focuses on problem-solving by assigning group projects based on students' experience with the immersive environments. The fundamental idea is to examine if the collaboration process will help students build a deep understanding of the subject by cycling through their experience and reflecting on their interaction with the environment.

Figure 1 : Students using AR-Skope application during group meeting in Experimental Group.

Thus, one of our approaches is to look at how students perceive the collaborative process and collaborative work, before they experience it within their pre-assigned groups, during and afterwards, with a focus on gathering and implementing formative assessments for improved collaborative experiences.

Experiment and Application Design

The Skope Learning Environment is comprised of three components 1) AR- and VR Skope applications, 2) A curriculum and assessment plan, and 3) A supporting website, containing learning modules. The following briefly describes each component of the project:

AR and VR Application

Figure 2: AR-Skope application's interface showing navigation instructions.

Both AR and VR applications provide a game like virtual environment that produce the experience of a walk-through of the building with augmented information and lessons. They provide a 3D interactive and annotated environment for visual understanding of the building's metrics, details and processes that are not visible in real-time such as the construction process, sun angles, water collection mechanism, and structural assemblies.

However, a key difference between these applications is that AR-Skope is location sensitive whereas VR-Skope is not. The VR application is designed as a first-person game experience allowing the students experience the virtual walk through from any remote location. The AR-Skope is an augmentation of a virtual world on top of the real environment, requiring the user's physical attendance on site.

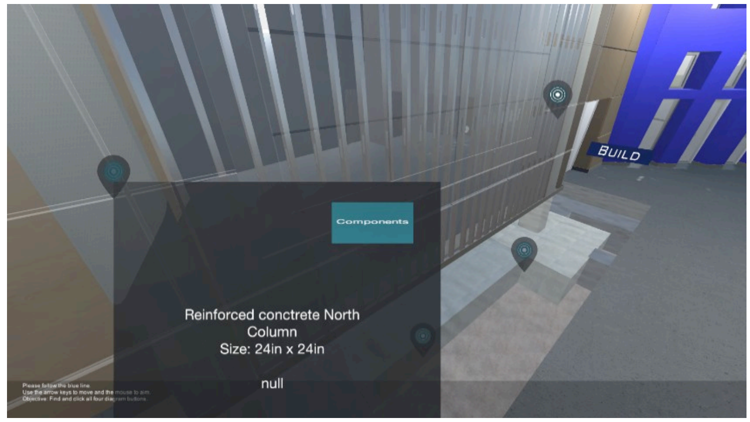

Figure 3: VR-Skope text box with labeled material of clicked building components.

Another significant difference between the two applications is that the AR application is developed using minimum virtual overlays since it utilizes the real world to complete the experience (see Figure 2). The VR environment relies on a complete textured virtual model requiring a fully developed environment with appropriate lighting, walking pace and height of the virtual user (see Figures 3 and 4).

Figure 4: VR-Skope applicaiton's on demand interactive similation of the sun angles.

Curriculum and Assessment

The project assessment was designed to engage three independent courses across disciplines of Architecture, Construction, and Mechanical Engineering at FIU for three consecutive semesters in an organized experiment. The first experiment began in the spring semester of 2016, which served as the "Control Group" for the project. The students taking courses in the fall semester of 2016 became the first experimental group or "Experimental Group 1". The third group of students taking courses in Spring 2017 served as the "Experimental Group 2".

To facilitate participation of students and faculty in these courses, the core content and scheduling of the courses was not significantly altered. All courses were taught within their home departments and discipline-specific instructors. The critical intervention was in reorganization of the course content and creation of interdisciplinary projects built around principles of sustainability and resiliency of buildings. In all courses, the curriculum was divided into three-five week units of: 1) Building Siting and Foundation, 2) Building Envelope and Mechanical Systems, and 3) Construction and Post-Occupancy Evaluation. In cases that the content was not a part of the original disciplinary courses, it was added by guest lectures, video recordings and posted materials the project website.

The Control Group

Upon completion of each unit, students were given a *collaborative project.* Students from each course were randomly assigned to interdisciplinary groups such that each group had at least one student from each course (and major). A total of 56 students were assigned to 11 different groups, resulting in average of 5 students per interdisciplinary group. These projects were the main vehicle for student collaboration.

The group projects were scenario driven, designed to focus on environmental sustainability features of a selected building on FIU's campus. The projects asked students to investigate the building by investigating its various systems and their energy efficiency, evaluating the building's carbon-foot print and studying its construction processes. The groups were to suggest alternatives to the existing building systems if necessary.

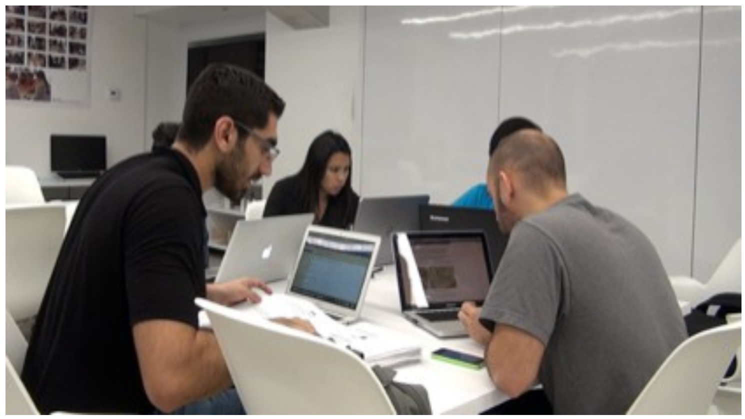

Figure 5: Control Group Interdisciplinary group

Each group was provided with the required building information and was assigned the task of physically visiting the building on campus. Students were to meet outside the classroom as a group several times for conducting each project. Thus, the group was expected to understand the issues, compare notes and discuss their observations and findings during meetings, plan their approach, and respond to the project scenario with the submission of a "Technical Report".

Experimental Group 1

A total of 88 students participated as part of Experimental Group 1. Students went through the same experience as the Control Group. The only significant difference was that they were provided with preliminary prototypes of the AR-Skope application. Students were encouraged to use and test the application to obtain information and learn about the building while they were working on their interdisciplinary Collaborative Projects.

Experimental Group 2

There was a total of 112 student participants in Experimental Group 2. These students were provided with the same course content and the experiment processes as the Control Group and Experimental Group 1, but incorporated the use of a more advanced version of the AR-Skope, as well the VR-Skope. The students were asked to walk to a building on campus and activate the application. Using the application, they were able to experience and interact with a building, view through the construction materials as if they had an x-ray vision, and query information based on demand. Again, students were asked to use and discuss their experience in addressing the question on their Collaborative Projects.

Data Collection and Assessment

To better plan the project activities, design effective applications, assess and improve collaborative learning, and assess the project impact on student learning, the project team gathered various types of data. These included: 1) *Pretest and Post-Test* designed to examine domain knowledge and analytical reasoning at the beginning and at the end of each semester, 2) *Pre and Post Attitude Surveys* used to gauge students' attitude towards collaborating with peers and students' motivation for interdisciplinary learning, 3) *technical reports*, which are the students' response to Interdisciplinary Collaborative Projects, used to evaluate student learning based on collaboration, and 4) *Video and Interviews* to observe student interaction and feedback on the project progress and direction. Data from items 2 and 4 were primarily used to evaluate students' collaborative work and interactions. In addition, they were used as the basis for formative assessments used to improve applications and the collaborative process.

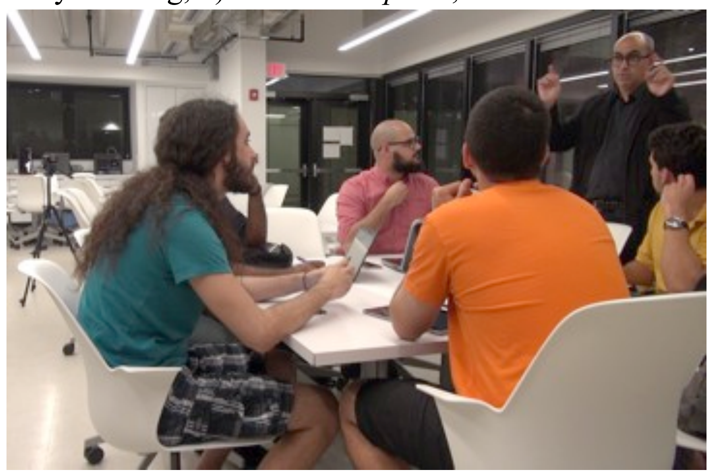

Figure 6: Student Interaction while discussing the project

Formative Evaluation of Within Group Collaboration -The evaluation and assessment focus was on observing and understanding the interaction, collaboration and group approach in completion of the Technical Reports. Our key approach was to provide iterative and just-in-time feedback to the students regarding collaborative efforts, questions asked, and process-based evaluations. A random subset of groups was video recorded and participated in exit interviews. Feedback and results were also used to update and alter assignment requirements, as well as process instructions and resources in the subsequent group projects.

Formative Improvements

As was discussed above and in more detail in Davis et al [16], a formative assessment was conducted to gain insight into students' challenges and implement changes that would positively impact student collaborations. Based on these prior results, the following changes were applied to the implementation of the AR-Skope application and Virtual Reality walkthroughs to support interdisciplinary collaborative work for Experimental Groups 1 and 2:

- **Communication** – To ensure more consistent and reliable communication, more structured, scheduled, and responsive communication efforts were implemented *within* the project requirements guided by the instructors and graduate assistants.

- **Enhanced Information Sharing** - This involved providing a website, blog, and teaching aids in the augmented reality and virtual reality walkthroughs for each project.
- **Within Group Collaboration** - During the first assignment, the technical reports were put together piecemeal instead of collaboratively. To resolve this, additional required scheduled meetings were added where the instructors and the graduate assistants could observe each group's interactions and provide additional guidance and feedback.

To gauge the impact of these formative changes, students in all three groups (Control Group, Experimental Group 1, and Experimental Group 2) were administered Pre- and Post-Attitude Surveys on their views of collaborative learning. Although engagement in collaborative learning was a focus of the formative assessment, we were also interested in investigating whether use of the technologies in combination with collaborative learning approaches would impact student attitudes and motivate them to engage in further collaborative learning.

Pre-Attitude surveys were administered at the beginning of the semester, prior to the commencement of any group work, and Post-Attitude surveys were administered at the end of the semester. The survey consisted of 13 questions using a 5-point Likert scale, where responses ranged from Strongly Disagree to Strongly Agree. An overall score was calculated for each participant by converting the response for each question to an integer ranging from 1-5, and adding together the individual scores from each question.

Results

A mixed model repeated measures ANOVA was conducted to compare the effect of Group (*Control Group*, *Experimental Group 1* and *Experimental Group 2*) on Test (Pre-/Post-Collaborative Learning Attitude Score) (DV). Main effects of Test, $F(1,255) = 61.24$ $p < .01$, $\eta^2_{partial} = .194$, and Group, $F(2,255) = 5.43$ $p = .005$, $\eta^2_{partial} = .041$, were found.

Overall, results indicate that students in all three groups (*Control Group*, *Experimental Group 1* and *Experimental Group 2*) indicated a decrease in their attitude towards collaborative learning from the Pre-Attitude ($M = 48.57$, $SD = 0.66$) to Post-Attitude ($M = 40.24$, $SD = 1.08$) surveys. As can be seen in Table 1, this pattern is consistent across each of the questions of the survey. This finding is not surprising given the cross-domain nature of our study, but it also does not tell the whole story.

	Collaboration Pretests			Collaboration Posttest		
Question	**Control**	**Exp 1**	**Exp 2**	**Control**	**Exp 1**	**Exp 2**
When I work together with others, I achieve more than when I work alone.	3.69	3.63	3.7	3.03	3.23	3.08
I willingly participate in cooperative learning activities.	3.91	4.11	4.19	3.14	3.69	3.65
When I work with other students I achieve more than when I work alone.	3.65	3.69	3.5	3.05	3.1	3.04
Cooperative learning can improve my attitude towards work.	3.97	3.99	3.91	3.09	3.51	3.53
Cooperative learning helps me to socialize more.	3.89	4.15	4.28	3.22	3.61	3.87
Cooperative learning enhances good working relationships among students.	3.86	4.07	4.28	3.23	3.51	3.7
Cooperative learning enhances class participation.	3.83	4.15	3.98	3.05	3.52	3.46
Creativity is facilitated in the group setting.	3.78	3.89	3.96	3.16	3.45	3.41
Group activities make the learning experience easier.	3.6	3.81	3.85	2.84	3.27	3.21
I learn to work with students who are different from me.	3.86	4.01	3.95	3.37	3.8	3.56
I enjoy the material more when I work with other students.	3.35	3.62	3.31	2.59	3.1	2.89
My work is better organized when I am in a group.	3.12	3.34	2.92	2.59	2.97	2.72
I prefer that my teachers use more group activities / assignments.	3.12	3.45	3.37	2.63	2.76	2.85

Table 1: Mean Pre- and Post-Attitude Scores for the Control Group, Experimental Group 1 and Experimental Group 2

To better understand the formative influences on participants' attitudes, the significant interactions discussed above found should be explored more closely. Follow up ANOVAs found significant differences for the Posttest between Groups, $F(2,255) = 5.71$ $p = .004$, $\eta^2_{partial} = .043$.

There were no significant differences found for the Pretest. Post hoc tests using the Least Significant Difference revealed a significant difference between the *Control Group* (M = 34.77, SD = 2.21) and both *Experimental Group 1* (M =43.91, SD = 1.66) Posttests (p = .01) and *Experimental Group 2* (M = 42.03, SD = 1.70) Posttests (p = .011). This illustrates an improvement in post-Attitude scores after the inclusion of changes to improve and enhance collaborative approaches along with the use of AR- and VR-Skope.

Summary and Conclusions

Collaborative learning that involves cross-domain and interdisciplinary interactions can be challenging to implement. Our findings indicate that with the appropriate guidance and tools in place, AR- Skope and VR- Skope enhanced collaborative learning and have the potential to improve interdisciplinary interactions in the building sciences, particularly in the areas of interdisciplinary team interactions, collaborative learning, and technology adaptation in building design and construction.

By making changes based on prior formative assessment results, more structured and improved communication enhanced information sharing. In addition, within group collaborations, with the implementation of AR-Skope and VR-Skope, better promotion of interdisciplinary, collaborative work was achieved. Using Skope learning environments, this study examined the value of VR, AR, visual simulations, and interactive lessons in support of collaborative learning in building sciences and architecture.

Our study involved the use of pre- and post-attitude surveys to determine the efficacy of combining formative changes and the implementation of AR-Skope and VR-Skope. Results of the attitude survey indicated that the proposed approach can effectively mitigate the decreases in students' negative attitude toward collaborative learning that are often found when engaging in cross-domain collaborations. Although a negative trend still existed, overall, the Skope learning system successfully achieved the goal of improving interdisciplinary team interactions and collaborative learning for students from architecture, construction, and mechanical engineering. Future work will include more formative assessments and implementations into the collaborative learning process, as well as associated enhancements to the AR- and VR-Skope technologies to support improved collaborative approaches.

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