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Immersive Learning for Sustainable Building Design and Construction Practices

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Abstract: Educational opportunities for students addressing issues in sustainable built environments are evolving with new learning approaches. Our study asked if technology mediated learning environments using AR (augmented reality) can enhance student learning in the architecture and engineering disciplines. There were multiple study sites, two of them University of Arkansas and Florida International University are discussed. At each site, three collaborative projects were assigned to student teams during fall 2016. Students analyzed an existing building and developed alternative solutions based on improving energy performance. Our paper presents: (1) the research challenge related to the integration of immersive head-mounted display technology providing visual simulations and interactive lessons for interdisciplinary collaboration; and (2) the progress of Phase 1 consisting of our control group results run without the use of AR technology.

Key words: STEM Education, sustainability, augmented reality, cyberlearning, immersive learning.

1. Introduction

Developing new knowledge and building effective decision-making to address society's progressively complex problems demands collective intelligence that can only emerge from collaboration among experts with diverse disciplinary backgrounds. Research indicates clear advantages to literacy across the STEM (science, technology engineering and mathematics) disciplines. According to Zollman et al. [2], STEM learning within the classroom should be seen as a "meta-discipline", in which curricular areas are integrated to promote analysis and deepen understanding. They argue interdisciplinary work propels students to "deep learning" compared to surface learning. Responding to this challenge entails a holistic view and an understanding of a host of issues going beyond the borders of existing institutional and educational entities. Successful collaboration requires professionals who have the skills to engage in effective interdisciplinary environments. Interdisciplinarity is the "mindful involvement and integration" of several academic disciplines and methods to study a central problem or project and involves deep learning [19]. Deep learning engages underlying conceptual ideas and relationships whereas surface learning is more superficial and relies on more memorization [18]. Deep learning requires the ability to rely more on internalized ideas of what constitutes learning, to be less dependent on authority and to have confidence in what one thinks and does [4, 13, 18]. Our study seeks to gauge the effectiveness of interdisciplinary or collaborative learning using new technologies in the classroom, namely cyberlearning tools like head-mounted displays, tablets and other similar tools.

2. Method and Materials

To achieve this, we proposed to design and test a collaborative learning environment using a

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tablet-based augmented virtual reality application, “Eco-construction” or “Ecocon” supporting educational content for sustainable building design and construction for AEC (architecture, engineering, and construction) students. We expected to approach the project using the same technology at two sites of our study Florida International University (FIU) and the University of Arkansas (UA). Part of our formative evaluation after the initial technology development at FIU were changes in the UA approach to the AR. The project builds on collaborative problem solving strategies and experiential learning theory to examine the effectiveness of the AR (augmented reality) technologies used in communicating complex systems and processes of building design and construction to students.

Our project integrates AR with BIM (building information modeling), visual simulations, and interactive lessons to explore how these simulation technologies affect learning. The project’s specific goals are to:

(1) explore the opportunities and obstacles presented by the integration of immersive and simulation technologies in support of learning through collaborative problem solving;

(2) examine the impact of various strategies on improving the effectiveness of these technologies through a formative design process; and

(3) contribute to research on how people learn using technology-mediated environments by developing a better understanding of the various attributes of these technologies.

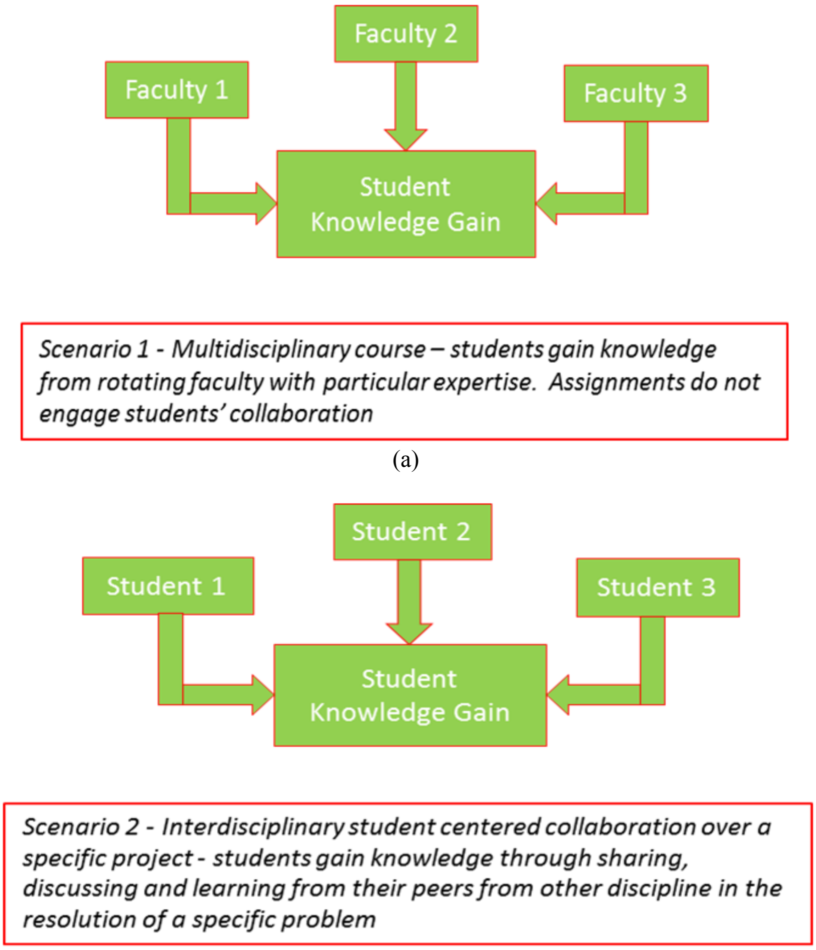
We identified three specific challenges to the traditional model enabled by cross-disciplinary interaction: (1) navigating knowledge silos; (2) developing critical thinking skills; and (3) improving interest and motivation for learning. For the first challenge, we recognize although not all integrative learning is interdisciplinary, all interdisciplinary knowledge is integrative. Interdisciplinary inquiry requires integrating knowledge, crossing boundaries between and among disciplines, being creative and innovative, reasoning by analogy, reasoning deductively, as well as the ability to synthesize [7]. Breaking down knowledge silos through collaborative interaction between architecture and engineering students is facilitated by interactive workshops given throughout the semester.

Developing critical thinking skills is a demonstrable outcome supported by numerous studies. Stimulating interest in the academic environment enhances learning and correlates with a multitude of academic and occupational outcomes including course selection, achievement, and persistence in a given field of study or career [1, 7, 8, 9, 17].

Sustainability used as the multifaceted subject of study in these courses, is one of the key topics gaining traction within the university. Davis Langdon’s research demonstrates: the cost/benefit analysis of implementing green strategies in buildings does not demand much investment and brings better returns. From his study, he concluded: “the costs of going green can be minimal (5% or less) and more than offset by future energy and carbon savings through bringing in the sustainability team from the beginning of a project, through performing proper energy modeling to choose the most cost-effective solutions to reducing energy use, and through including sustainability features in the earliest designs rather than ‘retrofitting’ them after some of the most important decisions have been made” [21].

The University of Arkansas is one of three sites for the implementation of a collaborative learning and problem solving for sustainability and green issues augmented reality grant. In the fall of 2016, students enrolled in the following courses gathered at Vol Walker Hall on the UA (University of Arkansas) campus for the first meeting. Eight multidisciplinary teams were formed with students from the School of Architecture (10 students) and College of Engineering departments of mechanical (23 students) and civil engineering (11) students.) The number of students per team ranged from five to seven. At least five meeting sessions were planned to promote interaction between students on their respective teams. They were expected to complete three technical reports over the course of the semester. Team members signed a collaborative agreement to share and discuss information, complete the analysis of the building under study, and submit three reports. The expectation of each team was to provide alternatives for improving the study building's performance as a function of energy consumption. While the goal of the long-term research is assessing collaboration between students in the AEC disciplines and learning in sustainable design associated with the integration of immersive technologies, the first phase is solely focused on collaborative multidisciplinary learning.

Among the variety of approaches deployed in effecting learning the most dominant is the interdisciplinary learning approached through two different strategies. The first strategy was to offer shared instruction for three unique courses. We selected a current core sustainability courses at the University of Arkansas as our shared site for collaboration. Students enrolled in unique courses assigned to their degree program, but were exposed to each of the three instructors throughout the semester. The syllabus included three pre-determined sections addressing site issues, building envelope design and LCA (life cycle analysis). The faculty rotated between the courses to deliver content for each shared portion of the syllabus (Fig. 1). Our second strategy consisted of bringing together students from different disciplinary



(a)

(b)

Fig. 1 Two possible scenarios showing organization of the learning experience: (a) Scenario 1; (b) Scenario 2.

backgrounds to collaborate on three specific projects. Assignments, namely the three technical reports, were given to each team of students to solve the problem through an interdisciplinary approach. Architecture students enrolled in ARCH 303v were taught by Professors Messadi and Newman, mechanical engineering students enrolled in MEEG 4473 by Professor Nutter and civil engineering students enrolled in CVEG 4863 were taught by Professor Braham. The teamwork was an opportunity for students to share knowledge through collaboration in solving a directed problem for each of the three areas covered in the syllabus. The goal of the technical report assignment was to make modifications to enhance the building performance and reduce the environmental impact of a new Vol Walker Hall extension, completed in 2008. We limited the area of study to a single 3rd floor classroom approximately 1,800 square feet in area. This allowed students to focus on specific building problems such as embodied heat, passive and active cooling strategies, mechanical systems and life cycle analysis of materials.

The content of the jointly offered courses focuses on building strategies to reduce energy consumption. Among all human activities contributing to climate change, the construction and operation of buildings is among the most energy, pollution, and resource intensive. Building and construction activities consume three billion tons of raw materials each year. Materials utilized in buildings have high-embodied energy, high-embodied emissions, and high levels of toxins and pollutants at the end of production [16]. Building design and construction impacts nearly every industry including architecture, planning, design, engineering, manufacturing, construction, transportation, labor, trade, and global commodity prices [15, 16]. Helping students in the AEC disciplines develop awareness of confidence in sustainable building practices has independent merit, combining this with the project to examine how collaborative learning using AR improves learning outcomes.

2.1 Goals of the Multi-phase Approach to This Research

Our primary and ongoing motivation for this project is to explore the affordances and limitations of collaborative learning using augmented reality in the STEM disciplines. We hypothesize the proposed project will help students become better equipped for interdisciplinary problem solving, be able to apply their knowledge into new situations, improve motivation and interest in their coursework—therefore increase their chances for retention and degree completion [10]. The specific focus of this project is to examine if Ecocon can improve students' problem-solving and collaborative learning skills leading to the design of more sustainable and better performing buildings. Extensive research shows learning technologies have the capacity to enhance learning. AR visualizations—the ability to overlay computer information onto the real world in real-time shared by multiple users—are critical in developing the next generation of computer-based learning environments [5, 6, 11, 12, 22]. Unlike computer interfaces drawing users away from the real world, AR technology enables interaction with the real world in ways never before possible [3]. AR has already transformed many professions such as medicine, military, aircraft navigation, entertainment, publishing, and education. However, the learning impact of fully integrated, and readily usable AR environments on face-to-face collaboration has not been sufficiently and systematically explored.

Building on advances in our understanding of learning processes and theoretical perspectives in CSCL (computer supported collaborative learning) research, this project examines how students engage with "mixed reality" and how a technology enhanced environment influences their interaction. Through the use of this framework the project team will explore the challenges and opportunities of this environments in an interdisciplinary setting by examining: (1) the typical patterns of collaborative interaction through the process of constructing a common shared object; (2) the impact of digital information overlay on objects on interdisciplinary negotiations and discussions; and (3) the learning outcome of the collaborating teams.

The research methodology employs formative evaluation to refine the experimental protocols after iterations of the interdisciplinary courses given at three universities: Florida International University, University of Arkansas, and Missouri State University. Given the AR application will be tested by groups of students from AEC disciplines working on common interdisciplinary assignments as part of their course workload, the adjustments will vary across the test-beds. Each team is maintaining a project journal and maintains contact during the semester process to evaluate any changes made in the experimental set-up. The basic project design follows an iterative approach based on a cyclic process of prototyping, analyzing, and testing for refinement. Students' interaction with the application and each other will be monitored, analyzed, and documented at each stage to inform revisions of the project.

2.2 University of Arkansas Approach

The initial control group for collaborative learning is currently underway in three courses from mechanical engineering, civil engineering, and architecture, respectively, directed by the PI (primary investigator) and three co-PIs at the University of Arkansas. Courses are taught separately by individual faculty but coordinated for evaluation of students using three technical projects throughout the semester. The semester work is divided into the following units focused on: (1) site and climate + building envelope; (2) building climate performance; (3) carbon footprint and life cycle analysis; and (4) LEED (leadership in energy and environmental design) certification for buildings. LEED is an ecology-oriented building certification program run under the auspices of the USGBC (U.S. Green Building Council). Upon completion of each unit—only the first three are considered here, students form interdisciplinary teams and engage in a one-day collaborative assignment. The three assigned projects demand the collaboration and participation of each student in the production of the technical report assigned for each unit of the semester. In our protocols, architecture students managed Project 1, mechanical engineering students led Project 2 and civil engineering students led Project 3. Students research, document and present their findings. In parallel, they are challenged, through the assigned projects to provide innovative ideas beyond the achieved results in the building. In each project, students pursue an in-depth study of a specific element and examine its performance with respect to sustainability. The results of each project will be submitted in the form of a report written according to the format specified in the assignment.

The current semester of the fall of 2016 is our control group—students are working collaboratively in the learning setting but not using any AR. As the FIU (Florida International University) team led by Prof. Shahin Vassigh discovered technical difficulties developing a tablet-based application for the augmented reality, we concurrently developed an approach using the Microsoft HoloLens, the Holoens-AR discussed here. The significant issue encountered by the FIU team was tolerances for GPS (Global Positioning System)-locating are not specific enough to allow real-time viewing to be overlaid by an image on a table. The augmented reality set-up was based on students using a hand-held device like a tablet or phone to view a real site while accessing an overlay of the structural or mechanical system of a building downloaded to their device through the internet (Fig. 2). The tolerances on the image-overlay are not supported by current GPS location. The GPS is a U.S.-owned utility providing users with PNT (positioning, navigation, and timing) services. This system consists of three segments: the space segment, the control segment, and the user segment [20]. In 2013, PS (position locations) accuracy was measured at $\leq$ 7.8 m

Fig. 2 Ecocon set-up using a handheld device proposed by the FIU team.

95% global average during normal operations. The system, managed by the U.S. Air Force, will continue to improve, however; the University of Arkansas team opted to use a recently developed HMD (head-mounted device), specifically the Microsoft HoloLens™ as a test for the AR portion of the experimental course.

The HoloLens shows images only the users wearing the glasses can access, however, images can be "shared" by users when all are wearing headsets. The onboard camera maps the users' position relative to the environment and places objects or overlays accordingly. Using Unity software, the UA team is developing an interactive experience for students based on a pre-identified room located in Vol Walker Hall on the UA campus. The software will allow students to "see" the computer-aided drawings produced by the building design team while standing in front of a wall surface using real-time images of the building under construction created by the CAST (Center for Advanced Spatial Technologies) directed by Jackson Cothren on the UA campus using LIDAR (light detection and ranging), a surveying method using pulsed laser light. The TESSERACT Center, under the direction of David Fredrick is working on the virtual environment with a team of architecture, computer science, and humanities students.

Pre- and post-survey questionnaires were administered to students. These consisted of a set of questions related to sustainable building practices (the course content) for students to answer prior to and at the end of the course. One set of survey data were tabulated and a statistical analysis will be performed to assess the significance of learning of sustainability through a conventional pedagogy. Next semester, students are introduced to AR tools in the same collaborative learning environment as the control group. The pre- and post-surveys will be administered again to gauge the impact of AR on learning.

3. Observed Benefits of Collaborative Learning for AEC Disciplines

In fall of 2016, students from the disciplines of architecture, mechanical and civil engineering enrolled in three independent courses (Fig. 3).

Fig. 3 Collaboration during a workshop demonstrating the way students assumed various roles including the "instructor" role. This was an interesting outcome of the workshop interactions and demonstrated the capacity of students to direct the learning experience.

Students in each course participated in a required workshop. Evaluation of their performance in their respective course was assessed through three collaborative assignments. Instructors taught their course separately but coordinated for a shared syllabus including the workshop and assignments. At this stage, students are working on Project 1. Teams were formed with students from across the three courses so each group had at least one student from each course (and major). A total of 44 students were assigned to eight different groups, resulting in 5-7 students per interdisciplinary group. As shown in Fig. 3, the architecture course focused on matters related to site, climate, daylighting, alternative energy sources, the mechanical engineering course concerntrated on theories related to building heating and cooling and the civil engineering course placed emphasis on the benefits of sustainability through life cycle analysis. Given the content of each course, the shared assignment was appropriate. The tasks divided into three sub-projects asking students to analyze, assess and modify an extension to a campus building using energy performance as benchmark criteria.

The building site selected for the student projects was the third floor of Vol Walker Hall extension, also known as the Steven L. Anderson Design Center located on the UA campus. Two large studios primarily occupy the third floor and between them is a critique area inclosed on one side by shafts for supply and return air and on the other by a shelf for printers. Two major shear walls running the full height of the building enclose a critique room on its north and south side. The envelope on the west side is primarily made of heat-insulated glass and an external shading layer of laminated frit glass louvers oriented northwest. In this way the face of the fritted louvers blocks the south and west solar impact. The envelope on the east side is a reinforced concrete shell with minimal openings. The roof and floor are built using a post-tensioned reinforced concrete slab with a raised floor to run all air ducts and plumbing.

These were scenario-based projects designed to focus on evaluating the sustainability features of a building, its environment and program demands located on a university campus. To accomplish this students were asked to meet outside the classroom as a group several times for each project. Each group was provided with all the required information on the building, and assigned the task of physically visiting the building on campus. In the first assignment students examined the site conditions and the performance of the exterior wall assembly. They were asked to develop alternate green strategies including material substitution, change in assembly or systems to improve building energy performance. The second assignment focused on testing opportunities for further substitution with green alternative energy and cleaner air quality by relying on the installation of one of the feasible renewable energy converting systems. Students assessed the opportunity for reducing the size of the HVAC (high voltage alternating current) system with its equipment and duct layout as a result of the use of alternative green energy. For the last assignment students conduct a life cycle analysis by comparing the base case building with the one purveyed with more performance systems. Two workshops are planned for each assignment. Students teams attend each of the workshops. During these workshops they collaborate on the three assignments while giving the team of faculty and other involved researchers the opportunity to observe and record the ongoing interaction. The entire session is videotaped and serves as the basis for the analysis conducted by the psychologist who is a member of the research team. Further, pre- and post-surveys are given to each student to gauge his/her learning about sustainability practices.

This fall 2016 is our initial offering or control group prior to the introduction of the AR technology. Students use a project-based approach where learning is planned around the investigation, explanation, and resolution of specific problems related to sustainability, green design and construction. With this approach students learn through by working through problems, thus learning centers on a complex situation or problem that does not have a single correct answer. Students

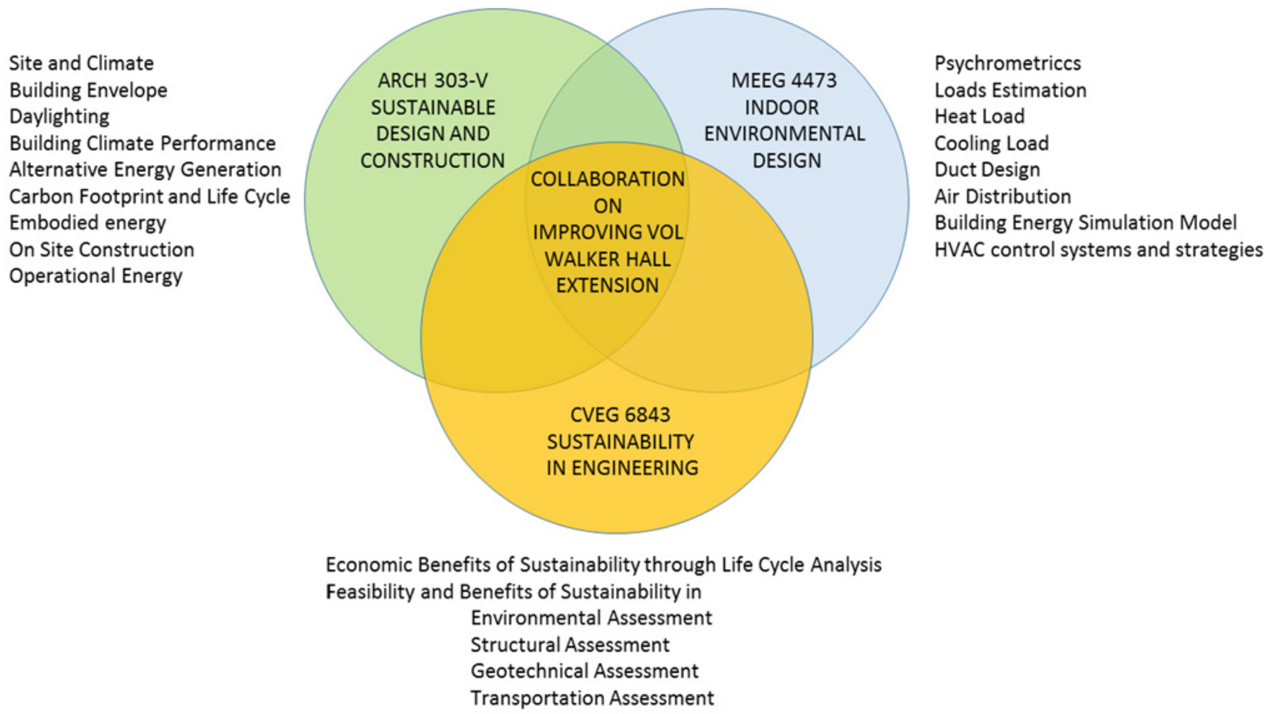


Fig. 4 Content of three separately taught courses showing areas of similarity and difference.

have to work collaboratively to identify what they need to learn to be able to solve a problem. Theoretical knowledge is learned as they work through the empirical application. The three assignments were designed to cover the range of significance issues in sustainability, giving students the opportunity to learn through solving multiple problems with direct connection to sustainable buildings (Fig. 4).

The project as described is the first part of a larger experimental study investigating the efficacy of cross-disciplinary collaborative approaches and tools. The focus of the first phase of the project was twofold: (1) first, to provide for a baseline understanding of challenges involved a cross-disciplinary collaborative approach integrating three courses on learning about sustainability of the built environment; and (2) second, to engage in formative assessment of the collaborative process itself to improve implementation of the collaborative work environment, building towards greater learning outcomes and student success. In this paper we discuss our approach, the formative process and the lessons learned for improvement.

In current practice, the design and construction of buildings is far too complex a task to be handled by a single professional. Becoming more and more considered sustainability is a broad domain and must be accounted for through an integrated approach in design and construction. Increasingly, research in education suggests sustainability must be recognized as a critical driver throughout all phases of a building design and construction process in order to achieve resource efficient, best performing and environmentally sensitive buildings [14].

In this scenario where the interdisciplinary collaboration was student-centered, the potential for learning was on multiple fronts. First, we observed students shared their "specialized" knowledge in the attempt to resolve a specific problem. In this setting each member of the collaborative team gains from the knowledge of other team members while solving a practical problem.

Second, students themselves are not very well acquainted with the mechanics of conducting teamwork, especially when it involves students from other disciplines. Hence, the value of collaboration and then how to actually collaborate had to be taught to students for them to comprehend the merits of this initiative. In the first encounters between students on a team, very little communication happened between them, but as they became more aware of the value of collaboration and more acquainted with each other, we witnessed then more interaction between them. We would note, despite recognized benefits achieved through collaboration, management issues and the logistical demands remain a challenge to the efficient operation of the team-taught collaborative courses.

Another challenge is to have other faculty buy-in into the initiative. While faculty were enthusiastic about the idea of collaboration they wanted autonomous control over their courses. Furthermore and as traditionally observed in the classroom, students are more responsive to their respective instructor. Students are therefore reluctant to comply with directions from other faculty running the workshop. From this experiment it became evident participation of the three faculty members is of critical importance to the effective running of the workshop.

At the time of this writing students are engaged in the preparation of Technical Report 1. The teaching staff are aware of the challenges faced by students in establishing a level of comfort working in teams as not only do not they know each other, they are from different disciplines. A get-to-know-you and information meeting was held to bring together faculty and students from the three courses. The first workshop was held during the architecture course class time with faculty present. We soon realized the difficulty students had finding a common meeting time for their required outside work sessions. This effected their eagerness and capacity to meet and is something we need to address for the next iteration of the collaborative course model. For the first assignment,

Fig. 5 Collaboration session between architecture, mechanical and civil engineering students working around a computer laptop.

architecture students took the lead. The work session proceeded and the interaction between students was recorded during the entire meeting time. Once they developed a working rapport, we observed various roles played by students including some students assuming the position of "instructor" during the work session (Fig. 3). We believe the teamwork continues to improve.

4. Conclusions and Future Work

In the course of our control group phase we learned a few formative improvements to encourage better collaboration among the teams' members. First, in the next iteration of the teaching semester we plan to schedule the three courses for the same time period so students won't need to plan for group meeting times outside of the class period.

As previously noted, this project is the first part of a larger experimental study investigating the efficacy of cross-disciplinary collaborative approaches and cyberlearning tools. Our future work uses our present formative findings to improve the next phase of the project in which we use an augmented reality learning application, the HoloLens-AR, to enable VR walkthroughs in the building. This VR experience will be designed to enhance and improve skills in interdisciplinary collaborative problem solving by enabling students to "see" various components hidden in the wall and floor systems as a virtual overlay. In addition to the formative assessment described, data collected from the current work also included pre- and post-tests, pre- and post-attitude surveys, student interaction videos and exit interviews (Fig. 5). Using analysis of this data, the efficacy of the use of the new technology will be tested experimentally against results with the current course offering acting as the control group.

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