Design and Assessment of a Mobile Augmented Reality-Based Information Delivery Tool for Construction and Civil Engineering Curriculum

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Abstract: The goal of the research reported in this paper is to design and systematically assess the effectiveness of a collaborative context-aware mobile augmented reality tool (CAM-ART) in construction and civil engineering curriculum. To achieve this goal, an augmented reality (AR)-based information delivery tool, CAM-ART, was implemented in classroom-scale experiments to enhance traditional lecture-based instruction and information delivery methods. In the research reported in this paper, the contents of an ordinary textbook were enhanced using computer-generated three-dimensional (3D) objects and other virtual multimedia (e.g., sound, video, and graphs), and delivered to students through an AR application running on their smartphones or tablet computers. The sample consisted of construction and civil engineering students, who were randomly assigned to Group A (control group) and Group B (test group). The designed learning tool was tested in a collaborative and interactive environment, preperformance and postperformance data was collected, and student perception of using the AR-based tool was elicited through a feedback questionnaire. Data analysis showed that CAM-ART had a measurable and positive impact on students’ learning both in short-term and long-term. Moreover, results of the feedback questionnaire indicated that students found CAM-ART to be an interesting, helpful, and motivational approach in the classroom that helped them gain more in-depth and long-lasting knowledge beyond what is normally expected from traditional lecture-based teaching methods. DOI: 10.1061/(ASCE)EI.1943-5541.0000229, © 2014 American Society of Civil Engineers.

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Introduction

Current State of Technology Integration with Higher Education

Despite previous research that points out the importance and value of technology in increasing the quality of learning, many higher education institutions are still investigating and experimenting technology advancements in relatively smaller scales and have much to learn about the turnover of educational technologies (Green and Gilbert 1995). Researchers have discussed that learning should occur in a blended environment where traditional classroom practices are combined with technological learning solutions (D’Souza et al. 2013). In contrast, the new generation of students is still being educated with old (and often outdated) teaching paradigms and methods (Beck and Wade 2006; Klopfer 2008; Prensky 2001) while they are growing up with information and communication technology (ICT) embedded in their daily lives. Compared to previous generations, the new technology savvy students handle digital information on a daily basis, are connected to others via mobile devices, work interactively, perform several tasks simultaneously, and play games in a more competitive and collaborative environment (Beck and Wade 2006; Kvavik and Caruso 2009).

Researchers have suggested that instrumental aids are one of the effective ways of controlling human learning (Skinner 1954). A study conducted by Virginia Tech and University of Georgia on approximately 1,400 university instructors indicated that most of the instructors felt that classroom technologies had a positive influence on their teaching and students’ learning. Respondents noted that technology has helped them deliver quality information, present more complicated examples to students, and enhance the engagement and attention of students in classroom activities (Brill and Galloway 2007). In another study, academicians showed a positive attitude towards ICT since it helped improve students’ integration (Gülbahar 2008). Hence, providing a supplementary pedagogical tool in addition to teachers’ guidance would be an ideal solution to effective learning. One of the main questions that must be properly addressed when deploying a new technology in the classroom is that if students can potentially do the same activities using this new technology (e.g., smartphones or tablet devices) does this also translate into better and more engaging learning with longer lasting results? To this end, an important issue is to use technology in an effective and proper way. Today’s students are always multiprocessoring by simultaneously performing several tasks such as listening to music, talking on their cell phones, and using computers. Some researchers have argued that in contrast to the common belief, multiprocessoring can in fact increase the attention span of students, if used properly (Brown 2000). Evidently and to support the prospect of situated and active learning (Brown et al. 1989; Lave and Wenger 1991; Lombardi 2007), mobile technologies that enable the ubiquitous and customized delivery of information can enhance the ability to learn and understand instructional materials. Many such handheld devices allow users to overlay

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Supportive Learning Theories and Human Learning System

Learning is defined as a change in knowledge attributable to experience (Schacter et al. 2009). According to Sawyer (2006), there are several contrasts between deep learning and traditional classroom practices that have dominated schooling for decades (Dewey 1959). Among those listed were the disconnection between class materials and what students already know, and understanding ideas that are not straight from the textbook. Prior to designing any learning tool, it is important to know how the human information processing system works. There are three fundamental principles in the science of learning, also known as cognitive theories of multimedia learning (Feuer et al. 2002), as follows: (1) dual channels which states that people have separate channels for processing verbal and visual materials, (2) limited capacity which means people can process limited amounts of material in each channel at any given time, and (3) active processing which indicates that meaningful learning occurs when learners are engaged in appropriate cognitive processing during the learning process. The cognitive theory of multimedia learning provides a basic description of how the human information processing system works. As shown in Fig. 1, there are three different memory stores which are known as (1) sensory memory which holds information in the same sensory format presented, has large capacity, but lasts only for a very brief time; (2) working memory which holds information in an organized format, has limited capacity, and lasts for a short period of time; and (3) long-term memory which holds information in an organized format, has large capacity, and lasts for long periods of time (Ebbinghaus 1964). In the research reported in this paper, CAM-ART allowed the information to be received via verbal and visual senses, transferred from sensory to working memory, and helped students integrate it with their prior knowledge and eventually transfer it to their long-term memory.

Moreover, according to several learning theories, metacognition is also a critical factor in the learning process, which refers to the learner’s knowledge of how to improve their own learning. This goal is achieved when the learners know the best way they learn (awareness) and how they could control their learning (control) (Hacker et al. 1998). In the research reported in this paper, a survey test was taken from 166 undergraduate students to gain a better understanding of students’ awareness about their learning style (Vincent and Ross 2001) and obtain feedback about the potential of using technology and mobile devices as a learning tool in the classroom. Results showed that students perceive visual information and technologies as an effective learning aid that can supplement traditional text-reading methods. Although such visual aids could also be provided through the use of simple slide presentations, the authors hypothesized that motivation could not be properly stimulated by simply adding visual presentations to course materials. The previously mentioned learning theories combined with the critical role of motivation in learning was the underlying reason behind selecting and using mobile AR as an innovative approach to combine traditional and technology-based course delivery techniques into a single platform. The developed tool provided a unique opportunity for students to use both their verbal and visual capabilities to learn better and more, as well as created a collaborative and interactive technology-based learning environment in the classroom by allowing discussions and teamwork (Nivala et al. 2012).

Learning Theories and Constructivism

Constructivism is one of the fundamental learning sciences which focuses on two critical aspects of learning: (1) social, and (2) cultural (Von Glasersfeld 1995). The two central ideas of constructivist theories are (1) learners are active in constructing their own knowledge, and (2) social interactions are important in the knowledge construction process (Bruning et al. 2011). Vygotski emphasized that social interaction coupled with cultural tools and activity shape individual development and learning (Vygotski 1978). In psychological (cognitive) constructivism, learning means individually possessing knowledge but in social constructivism, learning means belonging to a group and participating in the social construction of knowledge (Mason et al. 2007). Vygotski combined both psychological and social constructivism in the previously mentioned theory. The prospect of combining individual and social constructivism also served as the backbone of the research reported in this paper. In particular, using CAM-ART, students not only were able to work interactively in groups and under the instructor’s...
supervision in class, but also could use the tool individually at home to review and reinforce the class materials. Psychologists who emphasized the social construction of knowledge and situated learning, have affirmed Vygotsky's notion that learning is inherently social and embedded in a particular cultural setting (Cobb and Bowers 1999). Situated learning emphasizes that learning in the real world is different from studying in school. Situated learning is often described as enculturation or adopting the norms, behaviors, skills, beliefs, language, and attitudes of a particular community. In the research reported in this paper, the community is other students in the same class and in other words, a group of people that has particular ways of thinking and doing. The learning takes place by encouraging students to actively participate and use the tool (Greeno et al. 1996; Rogoff 1998). Researchers also listed collaboration as an effective learning method since it not only does help students adjust to others at an emotional level, but also serves to clarify a person’s thinking and ultimately help the student become more coherent and logical (Ginsburg and Oppen 1988). Studies also highlighted the importance of proper transfer of knowledge to the students so that they can benefit from what they learn and retain their skills for future applications in new situations (Schwartz et al. 2005). Knowledge transfer across contexts is especially difficult when a subject is taught only in a single context (Bjork and Richardson-Klavehn 1989). When a subject is taught in multiple contexts and includes examples that demonstrate wide application of what is being taught, people are more likely to abstract the relevant features of concepts and develop a flexible representation of knowledge (Gick and Holyoak 1983). As a result, designing and implementing an application to support multiple contexts can have a high impact on the learning process. Therefore, the authors also incorporated context-awareness into CAM-ART.

Research Methodology and Design

Mobile Augmented Reality and Education

Several researchers have reviewed the literature on technology and learning and concluded that if properly used, it can have great potential to enhance student achievement and teacher learning. It has been discussed that across people and situations, interactive simulations are more dominant for cognitive gain outcomes (Dede 1998; Vye et al. 1998; Yoon et al. 2012). Given that technologies for creating and displaying virtual objects and virtual environments have become more accessible and easier to use, the authors were motivated to test the potential of such technologies in real classrooms and assess if students learn better by using their mobile devices to gain access to contextual virtual information relevant to the course material. There are four types of virtual-real environments: (1) pure virtual reality (VR), (2) augmented virtuality (AV), (3) AR, and (4) reality (Milgram and Kishino 1994). In VR, the surrounding environment is completely digitalized. In AV, real objects are embedded into virtual ones. In AR visualization, 3D computer-generated objects and text are overlaid on top of the real world environment (Azuma 1997). Therefore, AR supplements reality rather than fully replacing it (Behzadan et al. 2008).

Although AR is not a new technology it still has a significant potential for use in information delivery systems and more specifically in education (Behzadan and Kamat 2013; Billinghurst 2002). Recently, several handheld AR learning systems have been devised to explore the effectiveness of this technology in learning. For instance, Billinghurst (2002) proposed a handheld AR educational application in which a virtual character teachers users about art history. Moreover, AR has recently been introduced in new application areas such as historical heritage reconstruction (Huang et al. 2009), training of operators of industrial processes (Schwald and De Laval 2003), system maintenance (Henderson and Feiner 2009), and tourist visits to museums and historic buildings (Wojcieszowski et al. 2004). As far as engineering education is concerned, previous studies used AR to enhance spatial abilities, an important component of human intelligence in math and geometry. For instance, Construct3D is a 3D geometric construction tool designed for mathematics and geometry education (Kaufmann 2003). In another research, an educational AR application was used for mechanical engineering teaching that allowed users to interact with 3D content using web technology and AR/VR techniques (Liarokapis et al. 2004). In architecture and construction, there have also been much work aimed at using simulation and multimedia as well as digital gaming to assist students to understand the components and processes of building technology and sustainable design (Maldovan and Messner 2005; Messner et al. 2005; Vassigh 2003, 2008; Vassigh and Herrera 2010). However, in construction and civil engineering, relatively few researchers have used AR-enhanced books and tabletop AR for student learning and training (Behzadan and Kamat 2012; Dong et al. 2013).

Background Presurvey

One of the reasons behind the increasing usage of AR in education and learning is that conducting hands-on experiments provides the opportunity for situated learning that is more likely to be applied to real world situations (Lave and Wenger 1991). AR can help combine the real world experience and the learning process, and thus create interactive and motivating learning experiences, which may result in more participation and group discussions even outside the classroom. As mentioned previously, in the research reported in this paper, a mobile context-aware AR tool called CAM-ART was designed and tested in an undergraduate course. Students were asked to use their handheld devices (i.e., smartphones or tablet computers) to receive context-aware virtual information about the materials presented in an ordinary course textbook, while working in groups in an interactive and collaborative setting. Through the use of mobile devices, the need for wearing bulky equipment such as AR head-mounted displays (HMDs) was also eliminated.

The first step of the project was to gain a more realistic understanding about the background knowledge of students, how they perceived the use of technology in the classroom, and what they thought about collaborative group work. Hence, a survey was conducted among 166 undergraduate (junior-level) students. In this survey, students (86% male and 14% female) responded to a multiple choice questionnaire regarding their prior knowledge about AR and VR, as well as how they felt about using an application on their mobile devices while working in a group. The survey also highlighted another interesting fact about the students by revealing that more than 90% of them owned a smartphone, a tablet device, or both which is a clear indication of how technology is embedded and plays an important role in students’ daily lives. These observations also verified that a great majority of students (90%) defined themselves as visual learners and more than 50% indicated that they would work better in a collaborative classroom setting. There are also other studies which verify that most engineering students are visual learners and learn better in more interactive learning environments (Dong et al. 2013; Felder and Silverman 1988). In addition, 24% of participants thought that compared to other engineering disciplines, technology has been used less in construction and civil engineering. In answering the same question, 58% were neutral which can be interpreted as an indication that many students do not have much idea about technology-based...
Table 1. Results of the Background Survey Conducted to Learn about Students’ Attitude towards Using Technology in a Collaborative Classroom Environment

<table>
<thead>
<tr>
<th>Question</th>
<th>Agree (%)</th>
<th>Neutral (%)</th>
<th>Disagree (%)</th>
</tr>
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<tbody>
<tr>
<td>Using a smartphone or tablet computer in the classroom for the purpose of learning the course material may be distracting</td>
<td>42</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>I am a visual learner. I learn better when the instructor uses 2D/3D visualization or multimedia to teach abstract engineering and scientific topics</td>
<td>90</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Compared to other engineering disciplines, instructors in construction and civil engineering use less technology in classroom</td>
<td>24</td>
<td>58</td>
<td>18</td>
</tr>
<tr>
<td>I learn better when working in a collaborative setting, e.g., working in a team, where I play a role in the learning process</td>
<td>52</td>
<td>29</td>
<td>19</td>
</tr>
</tbody>
</table>

classrooms. Moreover, as shown in Table 1, initially 42% of students claimed that using a smartphone or tablet computer in classroom could be distracting which can be due to the fact that they did not have the proper experience using these tools in support of learning. The survey also revealed that more than 80% of students had some or a clear idea about VR, and more than 70% of them had heard about AR but were not yet clear about it. These observations also proved the previous discussion that today’s students are more familiar with technology compared to previous generations.

Finally, in answering the survey questions, almost 80% of students responded that they were very confident about installing and using a mobile application on a smartphone or tablet device. Moreover, as stated in Table 2, almost half of the participants agreed that they were confident working in a group where each person could use their own mobile device. The results of this and other academic surveys (Dong et al. 2013; Felder and Silverman 1988) support the idea that using an interactive and collaborative pedagogical tool in engineering education can enhance the learning quality, increase students’ visual and practical knowledge, and help them match course concepts to real-world problems. The rest of this paper contains a detailed description of the mobile AR learning system design, as well as the implemented assessment strategies, and results and discussion.

**CAM-ART: System Design**

Educational researchers and practitioners have long been advocating the notion of 1:1 computing, which means equipping students with personal mobile devices and enabling 24/7 access so that the devices can mediate their classroom as well as out-of-classroom learning (Friedel et al. 2013). Various studies have provided designs for supporting student inquiry-based learning using mobile technologies (Roschelle et al. 2007; Spikol et al. 2009; Squire and Klopfer 2007; Vavoula et al. 2009). In order to develop an educational application, technological, domain-specific, and pedagogical aspects of the design have to be carefully considered. Context-aware systems featuring contextual data, engaging learning experiences, and improved learning effects have been applied to different learning activities (Cooper 1993). Dey (2001) defined context as contextual information about an entity, which may be a person, a place, or a physical object. This information is considered relevant to the interaction between a user and an application. In the research reported in this paper, the context-aware mobile AR platform, CAM-ART was created using an open-source, third-party, web-based programming environment (Junai 2012). Using this system-independent programming environment, the AR platform could be implemented without any need to create programming libraries (modules) and develop the entire mobile application from scratch. Also, this environment was an ideal choice because it allowed for rendering and displaying visual information in CAM-ART by providing on-demand access to a remote data repository, which eliminated the need to install or download large visual contents at once on individual mobile devices.

Several researchers have listed key principles of a good educational system design, as follows: (1) interaction, (2) empowerment, (3) awareness, (4) flexibility, (5) accessibility, (6) immediacy, and (7) minimalism (Cuendet et al. 2013). To have the most effective design, these principles should be instantiated through a participatory design with the teacher and tested in the classroom. Therefore, the authors incorporated all these principles in CAM-ART to enhance the quality of their pedagogical system. In particular, using the context-aware mobile AR application to display additional visual information on top of the textbook pages coupled with the teacher’s knowledge of the subject matter provides empowerment (Item 2) and awareness (Item 3). Moreover, the ability to use the tool individually or in a collaborative group setting provides interaction (Item 1) and flexibility (Item 4) in the design, by allowing students and teachers to work together to cope with varying levels of knowledge within a group or between the groups. With regard to accessibility (Item 5) and immediacy (Item 6), learners can immediately access audio and video learning materials anywhere and at any time, and receive immediate response from the AR tool as long as their handheld devices are connected to internet and they have their textbooks in front of them. Finally, minimalism (Item 7) in both the visualization features of the interface and the number of available functionalities was consistently observed in the system. Therefore, the research reported in this paper integrated teachers, textbooks, handheld AR, and information technology to construct a learning environment, in support of all seven design parameters listed previously.

Table 2. Level of Confidence among Students in Using a Mobile Device

<table>
<thead>
<tr>
<th>How confident do you feel to do the following</th>
<th>Very (%)</th>
<th>Not very (%)</th>
<th>Somewhat (%)</th>
<th>Not at all (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installing a mobile application on a smartphone or tablet device</td>
<td>79</td>
<td>2</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Using a mobile application on a smartphone or tablet device to get more information about a subject</td>
<td>81</td>
<td>2</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Working in a group where each student is using their own device to play a collaborative game related to the course topic</td>
<td>49</td>
<td>9</td>
<td>38</td>
<td>4</td>
</tr>
</tbody>
</table>
In the AR platform used in the research reported in this paper, an AR experience based on augmented reality experience language (AREL) consists of a static part, AREL extensible markup language (XML) which defines all the content and links, and a dynamic part, AREL JavaScript, which defines the interactions and behaviors of individual objects or the entire scene. The AREL has been used in Junaio and runs on both Android and iOS operating systems. An AREL package consists of the following components: (1) static XML for content definition, (2) Javascript logic to define interactions, and (3) content (that includes 3D objects, images, movies, and other multimedia). Using these components, end-user and server communicate over a wireless internet (Wi-Fi or 3G-4G) and the developer exchanges data with the server over hypertext transfer protocol (HTTP). All data processing and transfer methods used in CAM-ART were programmed in the hypertext preprocessor (PHP) language. The sequence diagram of CAM-ART is presented in Fig. 2. Before students study the contents of their textbooks, they use the built-in camera of their web-enabled handheld devices to scan a quick response (QR) code on the cover of the book.

Next, as they move their handheld devices over the images of the book, 3D computer generated and other multimedia (e.g., videos, sounds, and images) appear on top of the textbook images (Fig. 3). For instance, as shown in Fig. 3(c), after the instructor described how a split spoon sampler is used to take samples from the ground and showed the image of the book to the students, students could use CAM-ART to watch a real video of how exactly the task takes place on the jobsite. Displaying detailed two-dimensional (2D) images over the images of each drill bit such as diamond drill, rotary bit, and cross-chopping bit, as well as 3D models of the hand-operated augers are among other examples used for this scenario. Students can also collaboratively work with their peers to discuss the delivered information. The ability to use multiple devices at the same time in a group enhances participation and encourages interaction between group members. It also enables teachers to form teams of students and easily implement the tool in the classroom by asking students to use their own mobile devices at no additional cost.

**Assessment Techniques**

After properly designing the overall pedagogical framework and implementation strategies, the next step was to test the methodology in a classroom-scale setting by allowing students to experience with the newly developed technique, observing and collecting their performance data, and evaluate if any improvement to the learning process was evident. One of the challenges in educational research is generating assessment exercises that yield evidence enough to draw valid conclusions and interpretations about student learning.
(Sackett 1987). In order to address this challenge, a two-stage implementation procedure was used, as follows: (1) Stage 1 included single classroom testing of the pedagogical techniques, and (2) Stage 2 will include a collaborative effort among several universities and will assess the benefits of the developed learning tool in multiple courses (using larger and more diverse student populations). During Stage 1, the authors implemented CAM-ART in an undergraduate construction methods course offered every spring semester. In particular, as listed in Table 3, two mystery lectures were included in the course calendar and three different assessment steps were deployed.

Students (88% male and 12% female) were randomly divided into two groups (Groups A and B). Group A was used as the control group and asked to attend the first mystery lecture, and Group B was used as the test group and asked to attend the second mystery lecture. The two lectures were identical in terms of learning objectives and learning material, and differed in that only one allowed students to use CAM-ART. Students in both groups were not told ahead of time what to expect. This was essential to make sure that they came to class with minimum bias. However, as discussed previously, they were all given a presurvey questionnaire about 1 week prior to mystery lectures so that basic information (e.g., gender and program of study) as well as information about their level of familiarity with technical terms (e.g., VR and AR) and possession of certain tools (e.g., computers, tablets, and smartphones) could be collected. Each student was also assigned an identification (ID) number and the collected information was used to properly assign each student to either group. The topic of the lecture was selected to be construction site investigation. Group A (control group) only attended the first mystery lecture where material was delivered using conventional instruction methods including computer slides, lecture notes, and textbook. Students in this group were also allowed to discuss about the topics and visual information that they received during the lecture. Group B (test group), on the other hand, attended the second mystery lecture where the same topic was delivered using the CAM-ART. Group B was further divided into teams and each team was allowed to interact with the designed features of the CAM-ART on their own tablets or smartphones (Fig. 4).

As previously stated, an important implementation issue in these experiments was to establish appropriate techniques and guidelines to effectively assess the benefits of the new tool, and analyze its impacts on the learning process. To achieve this, and considering different aspects and limitations of available assessment techniques, the authors selected and used nine different classroom assessment techniques (CATs) as introduced by Angelo and Cross (1988) to systematically evaluate if the new learning platform has real practical benefits when used in classroom settings. The nine selected CATs included (1) background knowledge probe, (2) memory matrix, (3) categorizing grid, (4) defining features matrix, (5) approximate analogies, (6) course-related self-confidence surveys, (7) punctuated lectures, (8) teacher-designed feedback forms, and (9) group-work evaluations. Detailed descriptions of these CATs can be found in Angelo and Cross (1988).

Data Analysis and Results

Using the selected CATs, three similar assessment tests were given to each participating student both before and after the class, as well as 1 month later during the final course exam. To compare the results statistically, the $p$-value test was conducted. The $p$-value test is a statistical significance testing method which calculates the probability of obtaining a test statistic result at least as extreme as the one that was actually observed, with the assumption that the null hypothesis is true (Mendenhall and Sincich 1995). In this experiment, the null hypothesis was that both groups performed similarly. As shown in Table 4, in the posttest and long-term test, the mean grade and the standard deviation (SD) of the grades for both Groups A and B are very similar ($p$-value = 0.358 and 0.38,

<table>
<thead>
<tr>
<th>Task</th>
<th>Date</th>
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<tbody>
<tr>
<td>Presurvey questionnaire</td>
<td>Tuesday, March 26, 2013</td>
</tr>
<tr>
<td>Group A mystery lecture: prelecture test at the beginning of the lecture, deliver conventional lecture, and postlecture test at the end of the class</td>
<td>Tuesday, April 2, 2013</td>
</tr>
<tr>
<td>Group B mystery lecture: prelecture test at the beginning of the lecture, deliver lecture using the newly developed pedagogical tool, and postlecture test at the end of the class</td>
<td>Thursday, April 4, 2013</td>
</tr>
<tr>
<td>End of semester test: give the same test simultaneously to all students without their prior knowledge in about 1 month after the mystery lectures, at the final exam</td>
<td>Tuesday, April 30, 2013</td>
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<td>Tuesday, April 30, 2013</td>
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</table>
respectively). However, considering the pretest results, it is evident that Group A (control group) had a stronger background knowledge about the course topic compared to Group B (test group) with a p-value of 0.045 which is smaller than the predetermined significance level of the p-value test called alpha (alpha = 0.05).

The grades were out of 18 (Table 4). The Mann-Whitney test, which is a nonparametric statistics test, was used to compare the results. The null hypothesis in this test considers similarity of the two populations while the alternative hypothesis considers the other way, especially when the particular population tends to have larger values than the other (Mendenhall and Sincich 1995). The data used to conduct the Mann-Whitney test is presented in Table 5 and the results are presented in the subsequent subsections.

**Comparison of Pretest and Posttest Results**

In order to compare the results, the authors used the improvement percentage between each two tests. Eq. (1) was used to determine the improvement percentage for each student.

\[
\text{Improvement(\%)} = \frac{\text{Posttest grade} - \text{Pretest grade}}{\text{Pretest grade}} \times 100
\]

The following are the results of the Mann-Whitney test and confidence intervals (CIs) for Groups A and B.

Group A median: 38.1
Group B median: 100.0
Point estimate for ETA1-ETA2 is −61.9
The 95.7% CI for ETA1-ETA2 is (−150.0, 20.0)
Test of ETA1 = ETA2 versus ETA1 > ETA2
\[W = 49.0, \text{ cannot reject since } W \text{ is <64.0}\]

In these calculations, ETA refers to the median and W is the Wilcoxon rank sum test statistic. According to the results, the null hypothesis which states that values in Group B are larger than the ones in Group A cannot be rejected.

**Comparison of Pretest and Long-Term Test Results**

Similar to the previous case, the Mann-Whitney test was performed to compare the improvement between pretest and long-term test results. The improvement percentage was calculated according to Eq. (2)

<table>
<thead>
<tr>
<th>Pretest and posttest</th>
<th>Pretest and long-term test</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>AR</td>
</tr>
<tr>
<td>33</td>
<td>44</td>
</tr>
<tr>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>−10</td>
<td>140</td>
</tr>
<tr>
<td>120</td>
<td>63</td>
</tr>
<tr>
<td>220</td>
<td>100</td>
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<td>120</td>
<td>225</td>
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<tr>
<td>43</td>
<td>250</td>
</tr>
<tr>
<td>33</td>
<td>100</td>
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</table>

**Table 5. Improvement Percentage Values Calculated for Comparing the Pretest and Posttest, As Well As Pretest and Long-Term Test for Both Experiments**

**Fig. 5.** Student responses to sample statements from the postexperiment questionnaire: (a) describe the impact of CAM-ART on your learning; (b) how do you rate your learning experience today; (c) how likely is it that you recommend this tool to other schoolmates and instructors?
The following are the results of the Mann-Whitney test and confidence intervals (CIs) for Groups A and B.

- Group A long-term median: 38.1
- Group B long-term median: 77.8
- Point estimate for ETA1-ETA2 is \(-35.5\)
- The 95.7% CI for ETA1-ETA2 is \((-106.7, 17.9)\)
- Test of ETA1 = ETA2 versus ETA1 > ETA2
- \(W = 51.0\) cannot reject since \(W < 84.0\)

Again, the null hypothesis which states that values in Group B are larger than the ones in Group A cannot be rejected. The obtained values indicated a statistically significant difference between the improvement percentages of the group that carried out CAM-ART in the classroom (Group B). Consequently, an evaluation questionnaire was also given to Group B participants to evaluate their attitude towards using CAM-ART. The results of this questionnaire are discussed next.

**Evaluation**

At the end of the experiment, Group B students answered an evaluation (feedback) questionnaire regarding their attitude towards using CAM-ART and its impact on their learning experience. Results showed that students felt more interested in and motivated towards the topic, and mentioned that they experienced a much more interactive learning environment compared to traditional and lecture-based techniques. However, a few students mentioned that they had difficulty working simultaneously with CAM-ART and concentrating on the lecture. All in all, the majority of students in Group B were satisfied with the new AR learning tool. Fig. 5(a) shows student responses with regard to the impact of the CAM-ART on their learning experience. In addition and as shown in Figs. 5(b and c), the responses given to two five-point Likert scale questions revealed that most students rated the CAM-ART as a highly effective and highly recommended tool for use in other classes and by other instructors.

Another interesting observation obtained by analyzing the results was that students who used CAM-ART left fewer blank answers in both postlecture and final test compared to their prelecture test. As seen in Table 6, the total number of blank answers decreased by 45.8% in posttest and 47.2% in long-term tests for Group B students, almost twice the same measure for Group A students (24.3% for posttest and 20.8% for long-term tests). A non-blank answer is not necessarily a correct answer. However, knowing that Group A students started with a higher prior knowledge (less blank answers compared to Group B students), eventually Group B caught up and ended up leaving less blank answers in the long-term period. This was perceived as a good indicator that test Group B gained more self-confidence and better technical knowledge after using CAM-ART.

### Discussions and Conclusions

Taking into account the results of performance data analysis, it can be concluded that CAM-ART has exhibited a high potential for use as an effective pedagogical tool to supplement the traditional classroom setting and ordinary textbooks. However, one should not lose sight of the potential pitfalls of using technology in the classroom. For instance, Dede and Barab (2009) mentioned in their experiments that teachers and students found AR tools interactive, situational, collaborative, and highly engaging. However, they suggested that while AR provided potentially transformative added value, it simultaneously presented unique technological, managerial, and cognitive challenges to teaching and learning. This immersive interface thus illustrates both considerable potential and complex challenges to implementation. Hence, all of these strategies should engage learners as active participants in their learning by focusing their attention on critical elements, encouraging abstraction of common themes or procedures (principles), and evaluating their own progress toward understanding.

The goal of the research reported in this paper was to design, implement, and systematically assess a context-aware mobile AR tool for construction and civil engineering. In particular, an ordinary textbook was enhanced using 3D and multimedia virtual information. The developed AR tool was used in an undergraduate-level course to test and evaluate its impacts on and benefits to students’ learning. The findings from the research reported in this paper suggested that CAM-ART can provide better learning support capabilities for barrier removal between students and technology in education. In addition, it provided an interactive workspace and encouraged collaboration and interaction between students and course contents by immersing participants in a multimedia-enabled learning environment. Future work will include collaboration among several universities to assess the benefits of CAM-ART in multiple courses using larger and more diverse student populations. Moreover, the authors are working on adding simulation and location-based capabilities to CAM-ART to be able to use it in a more interactive platform that supports playing simulated games designed to introduce students to complicated scenarios and problems. Research has shown that this can be an effective and engaging way to prepare students for real world experiences (Lindgren and Schwartz 2009; Ritella and Hakkarainen 2012).

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