# ASSESSING THE PEDAGOGICAL VALUE OF AUGMENTED REALITY-BASED LEARNING IN CONSTRUCTION ENGINEERING

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***ABSTRACT:*** *This paper presents the latest findings of authors' work in design and assessment of an augmented reality pedagogical tool for construction engineering education. Previous work has extensively discussed the need for suitable learning tools and information delivery methods to enhance the quality of engineering education. However, developing a methodology with measurable outcomes that can assist in transforming conventional instructional techniques is not a trivial task and requires a meticulous approach. Within the educational research community, it is commonly accepted that instrumental aids, if properly used, can be effective controllers of human learning. This prospect coupled with the fact that technological advancements and mobile tools have become ubiquitous parts of our lives, motivated the authors to explore the possibility of using smartphones and tablet devices as instrumental aids to improve the quality of classroom teaching and learning. In particular, a context-aware augmented reality application was used to create a pop-up book by superimposing 3D graphics (virtual models, animations) and multimedia (images, videos, sounds) over the pages of a construction engineering textbook. This enabled students to watch, interact with, and learn abstract topics in construction equipment and methods in multiple contexts. The hypothesis of this research is that by establishing a contextual connection between ordinary textbook materials and technologies that students use in their daily routines, student engagement in the learning process improves, students can focus their attention to critical concepts, and instructors will be able to better evaluate students' progress toward conceptual understanding. In this regard, effectively measuring knowledge transfer and metacognition plays a vital role. To achieve this, several assessment techniques such as teacher-designed feedback forms, group-work evaluations, pre- and post- surveys, and exam evaluations are used to assess all three aspects of the learning process (replicative, applicative, and interpretive). Results, technical discussions, and recommendations are provided in this paper.*

***KEYWORDS:*** *augmented reality, construction education, pedagogical, cognitive, collaboration, classroom assessment techniques, context-aware.*

## 1. INTRODUCTION

To many students who are pursuing degrees in science, technology, engineering, and math (STEM), instructional techniques that heavily rely on traditional methods (e.g. note taking, handouts, memorization) to convey basic knowledge and skills about fundamental theories and applications are considered obsolete and not engaging. The new generation of students is technology savvy with high knowledge of and interest in social media, mobile technologies, and strategy games (Friedrich et al. 2009). Several school systems have recently initiated plans to deploy various types of classroom technology aimed at providing students with higher quality education with long-lasting impact. However, studies indicate that using technology without a suitable pedagogical structure may not yield desired outcome and can even have negative impact on student learning and long-term knowledge retention (Cristia et al. 2012). Therefore, having a technology-based pedagogical learning tool besides traditional learning methods could potentially enhance the learning quality (Echeverría et al. 2012; Roschelle et al. 2010).

Among several classes of digital technology, Pan et al. (2006) discussed that using virtual learning applications may result in an efficient and effective learning. More recently, a growing number of schools and educational institutions have shown interest in adopting such technologies in order to create productive educational environments. It is very likely that within the next several years, instructional techniques that benefit from new emerging technologies such as virtual reality (VR) and augmented reality (AR) will become standard components of STEM education. Such techniques will better assist teachers to be more effective when explaining abstract topics, while providing students with a means to collaborate on a common problem which ultimately strengthens their teamwork, communication, and critical thinking skills. This paper presents the latest results of an ongoing research project which aims at exploring the potential of mobile context-aware AR in STEM education. For

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proof-of-concept experiments and to validate the usability of the developed methodology, different scenarios from the construction and civil engineering domains are used. However, as outlined later in this paper, the final product of this research is sought to be generalizable and thus, the application domain will be ultimately expanded to other STEM disciplines.

## 2. AUGMENTED REALITY: A BRIEF INTRODUCTION

AR generates three-dimensional (3D) virtual contents on top of the views of the real world and creates an interactive interface which includes both real world and virtual objects (Azuma 1997). In essence, AR can be simply defined as a visualization paradigm that combines digital information with the real world (Pence 2010).

Although the more widely known VR visualization technology has been used during the past several years in STEM education, researchers predict that very soon, AR will supersede VR in terms of widespread use and educational impact (Pence 2007). Studies also suggest that many people are still uncomfortable with navigating around and interacting with a fully virtual world (Pence 2010). To this end, one of the advantages of AR is that it does not completely eliminate the real world from a user's experience, and hence, users have a more realistic sense of presence in the visualization experiment. In addition, AR provides a convenient interface for constructivism and discovery-based learning, spatial understanding, and social interaction, while it allows users to learn through making mistakes without having to worry about real world consequences (Behzadan and Kamat 2012). In terms of key technological components, AR incorporates several important aspects of visualization research including but not limited to the proper alignment of real and virtual worlds (a.k.a. registration), and real time interaction and feedback (Behzadan and Kamat 2005; Martin-Gutierrez et al. 2012). While researchers are still working on the psychological aspects resulting from the integration of AR in education, several studies have so far validated the technological effectiveness of AR in the learning process (Lindgren 2012; Martin-Gutierrez et al. 2012).

## 3. RESEARCH MOTIVATION

This research is motivated by two important observations regarding the new generation of students: (1) technology is embedded in their daily tasks outside the classroom, and (2) they have easy access to mobile devices. It is almost impossible to separate students from their technology-enabled devices or ask them to think and act differently than how they do outside the classroom. Rather, a more reasonable approach is to find ways to create a seamless transition between the outside world and the classroom environment. Surprisingly, a large percentage of students already have a good knowledge of terms such as VR and AR, but cannot or do not know how to relate these tools to their learning experience.

The authors recently administered a student survey in an undergraduate (junior-level) construction and civil engineering class of 88 students. As shown in Figure 1, 89% of responders indicated that they owned a smartphone, a tablet device, or both. Out of this population, 88% were familiar with VR, and 37% were familiar with AR. A solid majority of respondents (94%) agreed that they would learn better if instructors used interactive visualization and animation in the classroom (see Figure 2). The same survey revealed that a large percentage of students were visual and/or kinesthetic learners. In addition, 51% of students suggested that they would learn better if they worked in a collaborative setting (e.g. working in a team) where they played a role in the learning process. The results of this survey implied that many students tend to learn better and faster in an environment where they can see physical models or visual representations of the abstract concepts they are taught, or carry out individual or team activities as opposed to just listening to a lecture.

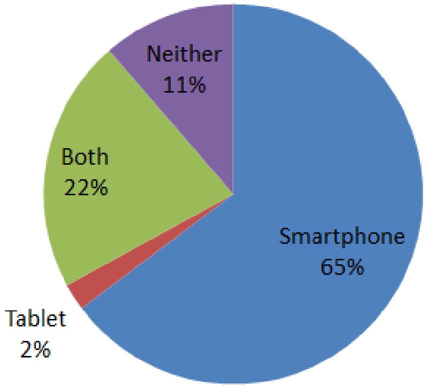



Fig. 1: The survey revealed that a large percentage of students own a smartphone, a tablet device, or both.

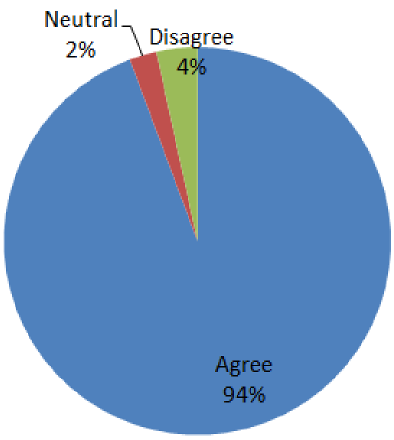



Fig. 2: A solid majority of students agreed to the statement: "I am a visual learner. I learn better when the instructor uses 2D/3D visualization or multimedia to teach abstract engineering and scientific topics".

In another study conducted by Felder and Silverman (1988), it was shown that most engineering students are visual and active learners. More recently, Dong et al. (2013) highlighted the same facts in their survey of undergraduate civil engineering students. These and similar studies justify the need for and present the unique opportunity to transform conventional pedagogical methods by taking advantage of recent technology advancements in an effort to help STEM students better relate the abstract knowledge they learn in the classroom to challenging problems they may face in the outside world. Interactive AR visualization applications can be effectively designed and launched on many existing small portable devices (e.g. smartphones, tablets, PDAs) to support this goal.

From a pedagogical perspective, an AR-based learning tool can draw students' attention by providing an easy-to-use and navigate interface, and creating a multi-user collaborative environment that enables natural interactions to enhance communication and better convey spatial cues (Chen 2006; Shelton and Hedley 2004). Other advantages of handheld AR which distinguish it from other visualization technologies are the portability of smartphones and tablets and that they are all equipped with built-in cameras (Kesim and Ozarslan 2012) that can be readily used to capture real world views.

## 4. LEARNING THEORY-BASED JUSTIFICATION

John Dewey (1859-1952) was an American psychologist and educational reformer who established the philosophy of pragmatism in education. Pragmatism is a philosophical term that describes the proper connection between practice and theory. It states that theory and practice continuously convert to one another, a cycle which is also referred to as intelligent practice. Existing methods of information delivery to students lack the intelligent practice aspect as they predominantly use (at best) a combination of computer slides and board work and do not fully support student participation in the discussions. Instructors who use these methods in classroom most often end up giving lectures while students are busy taking notes and trying to relate instructor's words to the contents of the slides. With this in mind, the authors applied the concept of intelligent practice to their work by providing students with context-aware AR pop-up books and asking them to collaboratively learn and practice the course material. This approach was reinforced by the prospect that through the presence of a social classroom environment and by allowing constructive discussion and collaboration between educators, a better alternative to the traditional teaching and learning experience can be created and deployed. Mayer and Moreno (1998) discussed that simply adding pictures to words does not guarantee an improvement in learning. Therefore, in this research, AR visualization was used to superimpose several other modes of multimedia information (including 2D and 3D models, videos, sounds) to potentially foster student learning.

Evidently, one of the pitfalls of relying too much on technology is that it does not necessarily guarantee effective learning and in fact, inappropriate use of technology can be distracting and even hinder learning (Bransford 2000). In light of this, in the presented work, digital technology such as smartphones and tablet devices is used not to replace the instructor but rather to supplement traditional instructional methods with new interactive technology. Another advantage of using this newly designed learning strategy is to shift the analytic focus from individual learners to group learners who participate in the social world and turn the cognitive process into a more encompassing view of social practice. Together, interactive learning and social interaction constitute what is commonly known as constructivism (Bruning et al. 1999).

It was anticipated that enhancing the contents of an ordinary textbook with computer-generated 2D and 3D models, still images, and other types of multimedia (e.g. movies, sounds) and using technologies such as smartphones and tablet devices to deliver such virtual information to the students would results in a more engaging learning experiment where students could ask more questions and gain more information. In addition, students who may have been overwhelmed by the sheer volume of information and course materials from other classes during the day would perceive this technology-enabled teaching environment as a different "out-of-the-box" setting which is more interesting to experience. Putting all these together, it was hypothesized that the new AR-based learning tool and the designed pedagogical methodology can bring every aspect of a successful learning process together, namely context, people, objects, and technology (Dewey 1959). As a result, educators will be better able to relate abstract theories to the real world problems, and take advantage of others' experience, thinking and reflection, interaction, and share in common life. Therefore, the lack of (1) organic connection, (2) motivation, and (3) connection between curriculum and real world, the three "evils" as suggested by Dewey (2010) will be eliminated.

Moreover, this research tried to investigate if using the new pedagogical tool could fulfill the three aspects of knowing, namely replicative, applicative, and interpretive through students responding to new information, participating in group work, and explaining the concepts to each other. To achieve this and considering Schwartz's theory about combining replicative, applicative, and interpretive aspects to achieve the best outcomes from the learning procedure (Schwartz et al. 2005), measures related to these three aspects were built in the designed assessment procedure and the effectiveness of the developed methodology in terms of short-term adaptability and long-term retention efficiency was evaluated.

## 5. METHODOLOGY

The main focus of the research presented in this paper is to design, implement, and assess an AR visualization platform that can be launched on mobile devices running on Android or iOS operating systems, and provide students with a means to see and interact with the contents of their textbooks. Since a mobile device provides the user with both input (through its built-in camera) and output (through its display) capabilities, the user does not have to wear extra peripheral devices such as AR goggles or head-mounted displays (HMDs) and thus, is less likely to be distracted during the learning experiment. The tangible product of this research is an AR pop-up book which in essence, is very similar to a traditional textbook but is enhanced with multimedia and context-aware 3D graphics capabilities. Students are able to use their books without the need to carry any additional devices or hardware. However, as shown in Figure 3, when looked at through a mobile device (e.g. smartphone, tablet), 3D graphics (models, animations) and multimedia (e.g. video, sound) corresponding to the content of each page is displayed to the student.

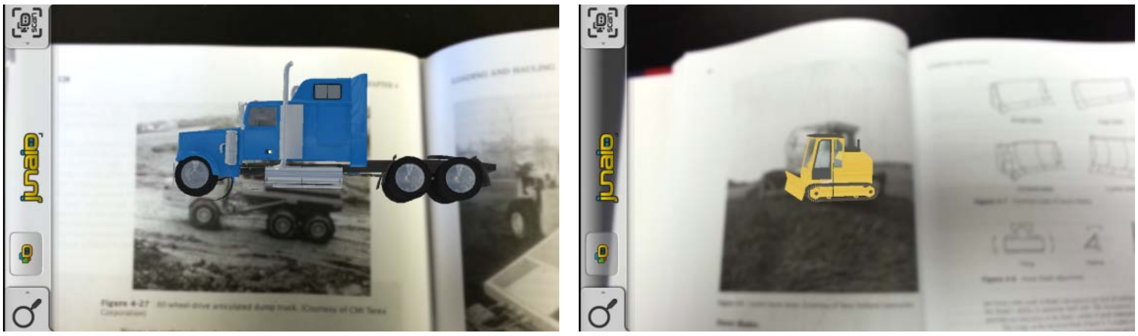



Fig. 3: Computer-generated virtual content is delivered to students via their mobile devices as they hover over different images of the textbook.

Using an AR pop-up book can be the first step to immerse students in their course topics. Billinghurst et a. (2001) showed that using an AR pop-up book results in collaboration in classrooms since it can bring together three levels of interaction: using a physical object, using an AR object, and immersing in a virtual space. In the following paragraphs, basic components of the developed platform are described in more detail:

*Scanning and Markers:* A key component of any AR application is accurate registration of virtual contents inside the real world space. Registration guarantees that real and virtual objects are always aligned inside the user's viewing frustum (Kamat and Behzadan 2006). There are two registration techniques that are commonly employed in AR: marker-less, and marker-based. In this research, the marker-based type is used. In particular, students first use their handheld devices to scan a 2D pattern (see Figure 4), which is known as a Quick Response (QR) code. The QR code helps identify the proper mapping between virtual information and the real world. Once the QR code is scanned and identified, subsequent scanning of predefined AR markers (a.k.a. tracking images) printed on the inside pages of the AR pop-up book will result in specific virtual contents superimposed on top of the markers. When the tracking image is visible through the device's camera, the corresponding virtual information is displayed to the student.

*AR Publishing Software:* In this research, an open-source third-party application for Android and iOS devices named Junaio was used as an entry point for developing and publishing context-aware AR experiments (Junaio 2012). Using this application, computer-generated information about different locations or objects can be linked via their corresponding channels. A channel is in fact a link to a remote server where the content is stored. Junaio employs two different channel types: location-based channels, and GLUE channels. When location-based channels are used, users can view the real world through the built-in camera of their mobile devices while the application overlays virtual information about points of interest (POIs) in the user's surrounding as soon as they fall within the user's viewing frustum. Users can hold their handheld devices up and look around to see virtual objects floating over different POIs. Using GLUE channels, on the other hand, one can attach or "glue" virtual 3D models, images or movies to any real world object. These 3D models can be linked to sound or video files as well as websites or images.

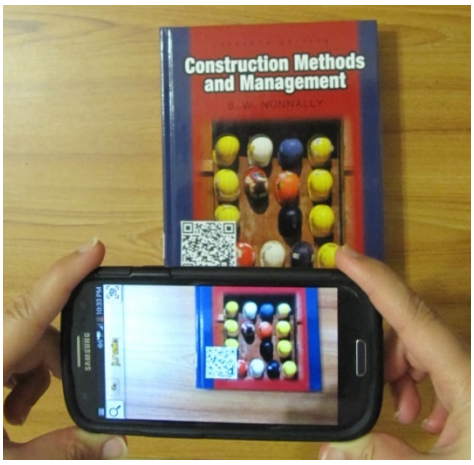
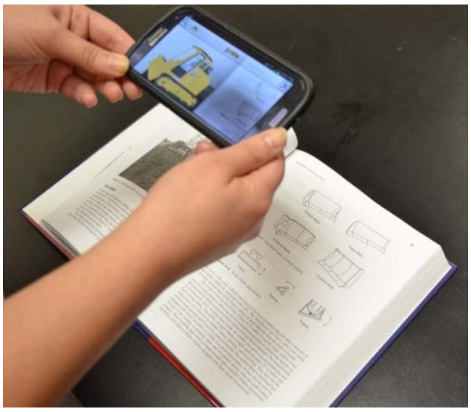



Fig. 4: Each student first scans a QR code using the built-in camera of his or her mobile device.

In this research, Junaio GLUE channels were used to create the AR interface of the AR pop-up book for construction and civil engineering students. The authors "enhanced" a sample chapter from a construction methods and management textbook (Nunnally 2007) by augmenting different types of virtual information (e.g. 3D models, videos, sound clips, and 2D images) on existing figures, tables, and diagrams (used as AR tracking images). Figure 5 shows snapshots of single-user and multiple-user feasibility experiments conducted using the developed mobile application.

A very important and convenient feature of the developed application is that all computer-generated virtual information are stored and updated on a host server maintained by the application developers. End users (i.e. students) do not need to download large volumes of information onto their mobile devices. Instead, they simply download and install a small application that will, in turn, communicate with the online data server and pull necessary information in real time. Given that students and instructors have easy access to Wi-Fi internet on campus and that 3G-4G mobile internet is becoming more widespread, this approach significantly reduces the processing time while giving application developers the flexibility to update or modify parts of the application from a remote server without having to physically access and run updates on each and every mobile device used by the students. The AR application is programmed using the Hypertext Preprocessor (PHP). PHP is a widely-used open source general-purpose scripting language that is especially suited for web development and can be embedded into the HyperText Markup Language (HTML).



(a) A single user views virtual contents overlaid on a book page.

(b) Two users simultaneously view virtual contents overlaid on two different pages.

Fig. 5: Computer-generated virtual content is superimposed and displayed over printed images of the textbook.

## 6. CLASSROOM ASSESSMENT PROCEDURE

After carefully designing the structure of the pedagogical framework and implementation strategies, the developed methodology was tested in a real classroom and student performance data was collected to evaluate if any potential improvement was achieved. In particular, a two-stage implementation process is planned for this research. In the first stage, the developed pedagogical technique is tested through several classroom experiments conducted in the authors' institution. The second stage (which is part of the future work) will include a collaborative effort among several educational institutions to assess the benefits of the developed learning tool in multiple courses using larger and more diverse student populations.

During the first stage of the assessment process, the authors implemented the mobile AR platform in an undergraduate course titled "CCE4004 – Construction Methods" offered every spring semester by the Department of Civil, Environmental, and Construction Engineering at the University of Central Florida (UCF). Two "mystery lectures" and three different assessments were performed. The course was offered in spring semester 2013 and had a total enrollment of 16 students. Table 1 shows the calendar of the assessment procedure. For the purpose of this experiment, "construction site investigation" was selected as the lecture topic. This topic was not previously covered in the course and thus, students were mostly unfamiliar with it. Also, students were not aware of the topic of mystery lectures nor did they know about the content of the other group's lecture prior to attending their own lecture. However, all 16 students were given a questionnaire about a week prior to the mystery lectures and basic personal information (e.g. gender, program of study), as well as information about their level of familiarity with some technical terms (e.g. VR, AR), and possession of computing devices (e.g. laptops, tablets, smartphones) were collected. Each student was assigned a random ID number and the collected information was used to better assign students to either group. Group A (control group) attended the first mystery lecture where material was delivered using conventional instructional methods such as PowerPoint slides, lecture notes, and ordinary textbook. Group B (test group), attended the second mystery lecture were the same topic was delivered using the developed AR-based information delivery platform and pop-up books. Group B was divided into teams of two people (a total of four teams) and each team was allowed to work collaboratively and interact with the designed features of the mobile platform on their own tablets or smartphones, as shown in Figure 6.

Table 1: Calendar of the assessment procedure

| **Assessment Component** | **Date** |
|---|---|
| *Pre-survey Questionnaire (16 students):*<br>Background information about program of study, gender, familiarity with terms such as VR and AR, and possession of mobile devices | Tuesday, March 26, 2013 |
| *Group A Mystery Lecture (8 students):*<br>Pre-lecture test at the beginning of the lecture, delivery of conventional lecture, post-lecture test at the end of the class | Tuesday, April 2, 2013 |
| *Group B Mystery Lecture (8 students):*<br>Pre-lecture test at the beginning of the lecture, delivery of lecture using the new AR and pedagogical tools, post-lecture test at the end of the class | Thursday, April 4, 2013 |
| *End of Semester Test (16 students):*<br>Give the same test simultaneously to all students without their prior knowledge about one month after the mystery lectures (at the final exam) | Tuesday, April 30, 2013 |

Group A – conventional lecture Group B – AR information delivery platform

Fig. 6: Two mystery lectures were conducted during the first stage of the assessment process.

In order to effectively assess the benefits of the new tool and analyze its impacts on the learning process, and considering different aspects and limitations of available assessment techniques, the authors selected nine different classroom assessment techniques (CATs) from a list of fifty standard CATs as introduced by Cross and Angelo (1988). Background knowledge probe, memory matrix, categorizing grid, and approximate analogies were among the techniques that were used. These CATs helped design an 18-question test that was used both prior and after each mystery lecture to systematically evaluate if the new AR-based learning tool had real and practical advantages when used in actual classroom settings. Also, as shown in Table 1, in addition to the pre- and post-lecture tests, an end-of-semester test including the same 18 questions was simultaneously given to all 16 students (without their prior knowledge) to assess if the knowledge they gained during the mystery lectures was retained with them in the longer term. Results and analysis are discussed in the next Section.

## 7. RESULTS

Figure 7 shows a summary of the analyzed data collected from students in Groups A and B. As shown in this Figure, students in Group A on average gave correct answers to 43% of the test questions prior to the lecture. After the lecture, the same test was given and this time, students on average gave correct answers to 67% of the questions. On the other hand, students in Group B on average gave correct answers to 29% of the test questions prior to the lecture. After the lecture, the same students on average gave correct answers to 69% of the questions. Through analyzing individual students' data, it was revealed that the performance of students in Group A on average improved by only 24%, while the same measure for Group B was about 40% (See Figure 8). In addition, as shown in Figure 7, when the same set of questions was given to all students one month later in order to evaluate long-term information retention, students in Group A gave correct answers to 62% of the questions while students in Group B answered 65% of the questions correctly. These results implied that compared to their post-lecture tests, Group A students retained 93% and Group B students retained 94% of the information in a period of one month.

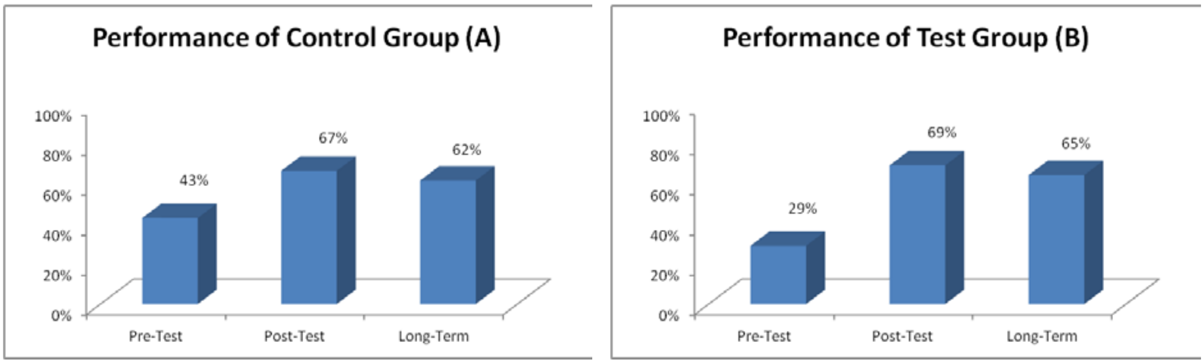



Fig. 7: Comparison of the pre- and post-test results as well as long-term retention of information for Group A (control group) and Group B (test group).

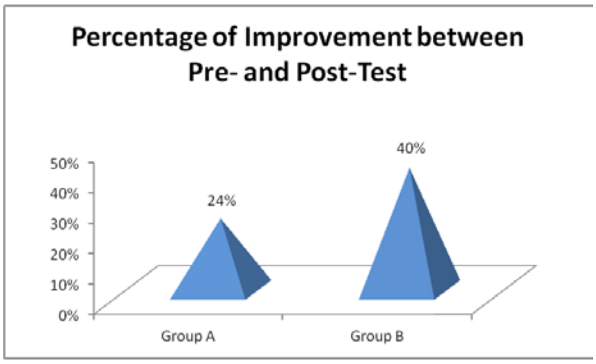
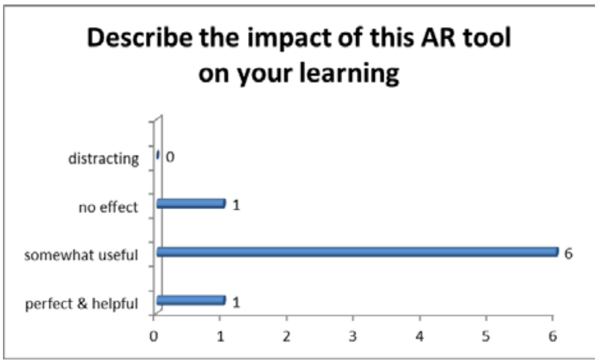



Fig. 8: Assessment results showed a higher performance improvement in Group B students who used the AR-based mobile platform to learn the course material.

In addition to performance data, students in Group B answered a series of questions about their perception of the AR-based learning tool upon the completion of the mystery lecture. These questions were designed using evaluation assessment techniques such as teacher-designed feedback forms and group-work evaluation. As shown in Figure 9, according to this survey, 7 out of 8 (i.e. 87.5%) students stated that the AR tool was "somewhat useful" or "perfect and helpful" in their learning. None of the students described the tool as being "distracting".



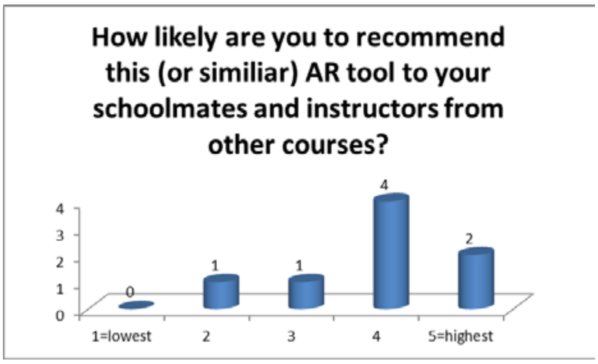




Fig. 9: Results of perception survey showed a significant interest in part of the students to use the developed AR-based learning tool in the classroom.

Using a 5-point Likert scale, collected data indicated that 77.5% of students (calculated by taking a weighted average of all responses) would recommend the use of this tool to their schoolmates and instructors in other courses.

## 8. CONCLUSIONS AND FUTURE WORK

It was observed that while today's students may have a very good knowledge and understanding about visualization technologies such as VR and AR, they are still not fully taking advantage of these tools in their learning process. In this paper, latest findings of an ongoing research project which aimed at using mobile context-aware AR in construction and civil engineering instruction were presented. In particular, the authors developed a pedagogical methodology for improving the quality of learning through transforming traditional instructional delivery techniques into technology-based learning. Students used their smartphones or tablet devices to download a small mobile application which enabled them to augment the contents of their textbooks by computer-generated information (e.g. 2D images, 3D models, movies, and sound). An academic assessment process to validate the effectiveness of the developed instructional material delivery technique was the next step. To this end, the authors conducted a pilot assessment study by dividing a class of 16 students into two groups. The control group (Group A) attended an ordinary lecture, while the test group (Group B) was asked to interact with the lecture material using their mobile devices and AR pop-up books. Data describing student performance was collected from both groups using several classroom assessment techniques adopted from Cross and Angelo (1988). The findings indicated that the performance of students in Group A was only improved by about 24% after attending the regular lecture while the performance of students in Group B was improved by more than 40% after attending the AR-enabled lecture. Further analysis also revealed that compared to their post-lecture tests, Group A students retained 93% and Group B students retained 94% of the information in a period of one month. Overall, data obtained from the developed assessment procedure showed that interactive mobile AR visualization tools coupled with a collaborative learning experience positively affected student learning. The authors are currently working on the design and implementation of several other experiments using larger and more diverse student populations. Ultimately, the findings of this research will be generalized and the application domain will be expanded to other STEM disciplines.

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