Teaching structural analysis with a mobile augmented reality application

by

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ABSTRACT

Structural analysis is a core course taught in every undergraduate civil engineering program and most architectural and construction engineering programs. Despite the critical role of this subject matter in engineering education, students usually have difficulty in grasping the abstract concepts, visualizing the deformed shape of simple structures, and relating basic structural members to more complex structural systems such as buildings and bridges. To help students to visualize the structural behaviors as well as linking structural representations with physical structures, a mobile augmented reality (AR) application, iStructAR, was developed. Through the application, a real campus building is superimposed with a virtual representation of the structure to demonstrate the concept of simply-supported beams. The application allows students to adjust the distributed load forces while observing the deflection shape of beams and reaction forces location and magnitude through the graphical representation of the building.

The AR application was piloted in a structural analysis course to assess whether a pedagogical approach involving AR technology is more effective than traditional lecture-based approach in learning structural analysis concepts. A quasi-experimental research design was performed, in which two sections of the course served as a control group (traditional lectures) and an experimental group (AR activity). Students' learning was measured using pretest and posttest. No significant difference was found in the pretest-posttest score change of control group and experimental group, which indicates that AR approach is equivalently effective to traditional lecture-based approach in learning structural analysis. A survey was also deployed to measure students' perceptions. The survey responses reported that most students held positive attitudes toward using AR to learn structural analysis. The students believed that the AR application was helpful for their learning and made learning more interesting.

CHAPTER 1. INTRODUCTION

Structural analysis is a fundamental and core course taught in every undergraduate civil engineering program and most architectural and construction engineering programs (Turkan, Radkowski, Karabulut-Ilgu, Behzadan, & Chen, 2017). It focuses on engineering mechanics, material science, and applied mathematics to determine structural deformation, internal forces, and structural support reactions (Pena & Chen, 2017). This course deals with high-level abstraction and difficult concepts such as force equilibrium and force transfer sense between structural members and their supports (Chou, Hsu, & Yao, 1997). Despite the critical role of this subject matter in civil engineering education, students usually have hard time to learn the subject matter content and are not well motivated to learn this subject (Chou et al., 1997). In particular, students have difficulty in grasping the abstract concepts, visualizing the deformed shape of simple structures, and relating basic structural members to more complex structural systems such as buildings and bridges (Chou et al., 1997; Turkan et al., 2017).

To address students' challenges in learning structural analysis, the instructional approach of teaching structural analysis has shifted with the advancement in technology. Hands-on methods of teaching structural analysis in traditional laboratory has historically been dominant in structural engineering education (Yuan & Teng, 2002). With the introduction of personal computers, computer simulations were later used to enable dynamic presentation of learning materials and make difficult visualizations possible (Chou et al., 1997; Feisel & Rosa, 2005). As computers have become increasingly common in teaching and the practice of structural engineering, many computer-aided packages have been developed to assist learning. Yuan and Teng (2002) developed an innovative Web-based package named CALSB, which allows users to build and test two-dimensional skeletal structures of unlimited choices in a virtual laboratory environment.

However, most of the current engineering curriculum still fails to provide students with opportunities for building connections between classroom and the real-life engineering practices (Turkan et al., 2017). In other words, students have difficulty in linking the physical structures with the traditional graphic representations they usually use in classrooms. Also, as Turken et al. (2017) suggested, too much emphasis has been placed on the analysis of individual structural members, which makes it difficult for students to comprehend and analyze complex structures with a large number of interconnected elements. Augmented Reality (AR) technology could be a good solution to address these learning challenges because it superimposes virtual elements on real objects and allows users to visualize which may not be possibly seen otherwise.

As one of the innovative instructional approaches, AR holds potential to improve student learning experiences and academic performance (Bujak et al., 2013). Researchers have reported the advantages of using AR applications in educational context such as improving learning outcomes (Yoon, Anderson, Lin, & Elinich, 2017; Shirazi & Behzadan, 2015; Lin, Duh, Li, Wang, & Tsai, 2013), increasing student motivation and engagement (Dunleavy, Dede, & Mitchell, 2009; Chen, Chou, & Huang 2013), and increasing knowledge retention (Pérez-López & Contero, 2013). However, the affordance of using AR in engineering education is less investigated compared to some other domains. In Bacca, Baldiris, Fabregat, and Graf's (2014) review study, only 5 out of 32 articles were identified in "Engineering, manufacturing and construction" education category. More research studies need to be carried out to investigate the use of AR in engineering education; in particular, to address the learning challenges of engineering students. Under this context, this study investigates the use of an AR application in a structural analysis course. The results of this study are expected to fill the gap in the literature as well as providing valuable insights for other engineering educators and researchers.

Research Questions

The purpose of this study is to investigate the learning effectiveness of a pedagogical approach involving augmented reality technology in teaching structural analysis. In addition, students' perceptions of using augmented reality to learn structural analysis concepts will also be examined. The results of this study are expected to inform the pedagogical decisions in designing learning activities involving augmented reality to improve student's structural analysis knowledge and skills. The following research questions will guide the study:

1. Does a pedagogical approach involving AR technology improve student's learning outcomes compared to traditional lecture-based approach in teaching structural analysis?
2. What are students' perceptions of using an AR application in learning structural analysis concepts?

Definition of Terms

Augmented Reality

Augmented Reality (AR) refers to technology that allows the coexistence of digital information and real environment (Azuma,1997). The digital information can include text, images, and videos (Yuen, Yaoyuneyong, & Johnson, 2011). By superimposing virtual elements onto the real-world environments, AR allows users to experience and perceive the newly incorporated information as part of their present world, thereby enhancing their perception of the real world (Yong et al, 2017). A few similar terms have been also mentioned in literature including mixed reality and virtual reality. To distinguish those terms, Milgram, Takemura, Utsumi, and Kishino (1995) introduced a Reality-Virtuality Continuum and defined four types of environments, as illustrated in Figure 1.1. The left end is Real Environment, which refers to any environment consisting solely of real objects. The opposite end is Virtual Environment, which consist solely of virtual objects such as computer-generated materials. Everything between these two opposite ends is defined as Mixed Reality. Augmented Reality, as described above, superimpose virtual elements onto the physical environment.

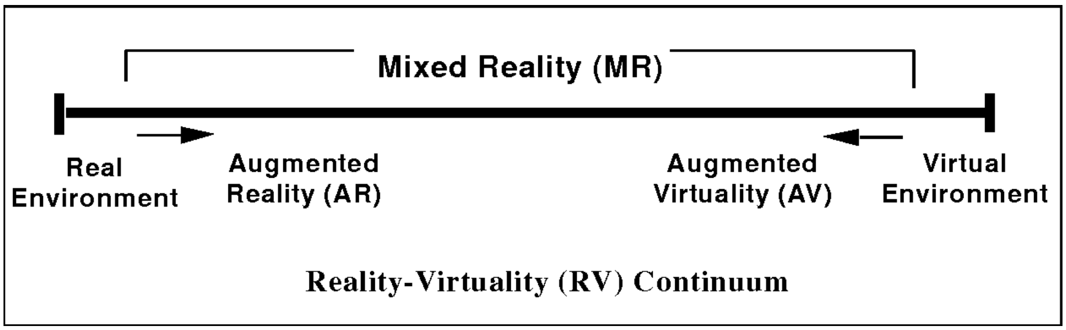

Figure 1. 1 Reality-Virtuality (RV) Continuum

Pedagogical Approach

Pedagogy refers to "the instructional techniques and strategies which enable learning to take place" (Siraj-Blatchford, et al., 2002). Particularly in this study, an AR activity was implemented as an alternative pedagogical approach to traditional lecture-based instruction to teach structural analysis. The AR activity involved the use of an AR application and a series of learning activities. A detailed description of the AR activity is provided in the methodology chapter.

Structural Analysis

Structural Analysis is a fundamental and core course taught in every undergraduate civil engineering program and most architectural and construction engineering programs (Turkan, Radkowski, Karabulut-Ilgu, Behzadan, & Chen, 2017). Particularly, in this study, Structural Analysis is a three-credits course in the Civil Engineering curriculum in the Department of Civil, Construction and Environmental Engineering at Iowa State University. In this course, students learn to analyze forces and displacements in determinate and indeterminate structures using both equilibrium and energy-based solutions. The specific concepts of structural analysis measured in this study include beams, types of loads (dead load, live load), deflection, and reaction force.

Learning Effectiveness

Learning effectiveness refers to “the degree to which learning outcomes have been achieved” (Blicker, 2005). In literature, learning effectiveness is commonly measured by student’s learning performance such as test scores, exam performance, and skill measurements (e.g. Zhang et al., 2006; Connor-Greene, 2000). In this study, an AR application was used during a course unit and the unit quizzes, as one of the major assessment instruments in the course, were used to measure the learning effectiveness.

Thesis Organization

This thesis consists of five chapters. Chapter one introduces the background and purpose of this thesis. Chapter two presents a systematic review of studies investigating the use of AR in engineering education. Chapter three describes the methodology used to conduct this research. Chapter four and five respectively summarizes the research results and general conclusions of this thesis. References cited are included at the end of each chapter.

CHAPTER 2. SYSTEMATIC REVIEW OF LITERATURE

Introduction

Augmented Reality (AR) refers to technology that allows the coexistence of digital information and real environment (Azuma,1997). By superimposing virtual elements onto the real-world environments, AR allows users to experience and perceive the newly incorporated information as part of their present world, thereby enhancing their perception of the real world (Yong et al, 2017). Given the great potential of AR in enhancing users' perceptions and improving productivity in realistic world tasks (Azuma et al., 2001; Schmalstieg, 2001), AR applications have been applied in several domains including advertising and marketing, architecture and construction, entertainment, medical, military, and travel (Yuen, Yaoyuneyong, Johnson, 2011).

AR has started to be applied in education in recent years (Küçük, Kapakin, & Göktaş, 2016). Yuen et al. (2011) identified five significant educational applications of AR technology: AR books, AR gaming, discovery-based learning, objects modeling, and skills training. It is believed that AR has vast potentials and numerous benefits to enhance teaching and learning (Billinghurst, 2002; Cooperstock, 2001; Shelton & Hedley, 2002; Yuen et al., 2011). For instance, AR technology has potential to: (1) foster student imagination and simplify complex concepts via 3D virtual model of physical objects (Sungkur, Panchoo, & Bhoyroo, 2016; Yuen et al., 2011), (2) offer interactive and engaging experiences (Lee, 2012; Yuen et al., 2011, Dede & Barab, 2009), 3) provide contextual information and learning experience, e.g. location-based AR in school field trips (Yuen et al., 2011), (4) provide multimedia-enabled learning experiences to support learners with different learning styles (Shirazi & Behzadan, 2014), (5) simulate close-to-realistic environments where students can conduct experiments with the help of virtual models representing physical system or scenario (Sungkur et al.,2016), and (6) teach subjects such as Astronomy where students could not feasibly gain first-hand experiences (Sheltonn & Heldley, 2002).

Considering the increasing use of AR technology in educational field and the growing body of literature on topics related to AR, several researchers have conducted review studies to summarize and evaluate the existing studies in literature (Martin et al., 2011; Radu, 2012; Radu, 2014; Santos et al., 2014; Becca et al., 2014). These review studies presented the status of research in AR in education through reporting the trends, effectiveness, affordances, advantages, limitations, or challenges of AR. However, most of them are cross-disciplinary review studies, which reported the aforementioned factors of AR in education in general. Far too little attention has been paid to the use of AR in specific subject field. Considering that each academic filed may have its unique curriculum, learning context, and learning challenges, it is necessary to examine the use of AR in specific fields. Such studies are expected to provide educators and researchers with more applicable and contextual insights. Particularly, in engineering education, no review study has been published yet to critically appraise and summarize the research about AR in engineering education to the knowledge of the author. Therefore, this review aims to fill the gap in the literature as well as informing future practice and research in using AR to teach engineering concepts.

Review Procedure

This review was conducted following the systematic review procedures introduced by Borrego, Foster, and Froyd (2014). Systematic review of literature is a research methodology that inform policy and practice by synthesizing primary studies in a field (Boerrego et al., 2014). Systematic reviews can also demonstrate gaps in recent work and identify future research directions by uncovering patterns, connections, relationship, and trends across multiple studies (Boerrego et al., 2014; Petticrew & Roberts, 2006). Generally, systematic review procedures involve selecting a collection of appropriate studies and making meaning from a set of primary studies (Boerrego et al., 2014).

Borrego et al. (2014) introduced an approach to systematic review specifically for engineering education. The procedures include (1) deciding to do a systematic review, (2) identifying scope and research questions, (3) defining inclusion criteria, (4) finding and cataloging sources, (5) critique and appraisal, and (6) Synthesis. This review follows these steps and more detailed procedures are described in the following sections.

Step 1: Deciding to Do a Systematic Review

Many of the benefits of AR mentioned previously can be leveraged in engineering education. For instance, engineering subjects involves many complex and abstract concepts such as structural behaviors, which are hard to visualize and understand via static graphic representations on blackboard or a paper. AR can help to foster student imagination and simplify the complex concepts by displaying representations in 2D or 3D from different angles. Also, AR can provide contextual learning experiences where students can get first-hand experiences and link their learning in classrooms to the real-world engineering industry practices. However, there is no comprehensive understanding of the use of AR in engineering education to provide practical guidance to leverage the benefits of AR in teaching engineering subjects. In other words, a general overall picture of the evidence in using AR in engineering education is needed to direct future research efforts. This is one of the situations proposed by Petticrew and Roberts (2006) that could warrant benefit from systematic review. Thus, in this situation, a systematic review would be beneficial and valuable.

Step 2: Identifying Scope and Research Questions

In consideration of the thesis' research questions, this review of literature only focused on the use of AR in formal higher education and context where students have physical interactions with AR tools. Thus, studies investigating the use of AR in distance education or other levels of education were not included in this review. The time span of article publication was also restricted to the recent 10 years because of the rapid advance of AR technology. In addition, the review only included studies with empirical data, which means the findings were based on observation or experiment, instead of pure theory. Empirical studies would provide evidence-based guidance for future studies.

Based on the review scope and the thesis' research questions, the following questions were identified and used to guide all other states of the review process:

1. What are the research trends of AR in engineering higher education?
   1.1. Number of studies published in each year from 2007-2017
   1.2. Distribution of studies in engineering majors
2. What are the evaluation approaches have been used to investigate AR in engineering higher education?
   2.1. Evaluation method
   2.2. Evaluation type
3. What are the benefits and challenges of using AR in engineering higher education?
   3.1. Reported benefits
   3.2. Reported challenges

Step 3: Defining Inclusion Criteria

As suggested by Borrego et al. (2014), at least three types of inclusion criteria need to be defined in this step. The criteria should address the research questions of this systematic review. The three types of criteria are described below.

Criteria for selecting databases. The first type is criteria for selecting databases. To ensure that relevant studies were identified, several types of databases listed in Borrego et al. (2014) were selected in this review. They are subject database (Eric, Educational Full Text and Compendex), general database (JSTOR and Web of Science), and journal database (Science Direct and Wiley).

Criteria for search keywords. The second type of criteria is a set of combinations of search words (phrases) and logical connectors (AND, OR), which is used to narrow down to a smaller set of articles (Borrego et al., 2014). The combinations used for search in this review were "augmented reality" AND "engineering" AND "education" or "mixed reality" AND "engineering" AND "education". The term "augmented reality" and "mixed reality" were both searched because the two terms are often used interchangeably in literature. Also, these two terms were only searched in the "abstract" instead of "full text" to exclude articles that mention the terms but whose main topic is not AR.

Criteria for article inclusion. The third type of criteria is more detailed inclusion criteria that guides the selection of articles. Articles that do not meet these criteria were excluded from the review. In this review, the following inclusion criteria were applied:

a) The study uses AR for instructional (teaching and learning) purpose;
b) Participants of the study are students in engineering programs in formal post-secondary educational settings;

c) Participants of the study have direct physical interactions with the AR apps (exclude distance education or remote lab)

d) The study includes empirical data

e) The study is published during 2007 to 2017;

f) The study is in English language.

Step 4: Finding and Cataloging Sources

During the initial search, the defined combinations of keywords and logical connectors were used to identify articles from the selected databases. To further winnow the articles and filter out the ones that do not meet the defined inclusion criteria, the timespan (2007-2017), language (English), publication type (academic journals) and document type (empirical articles) were also set up in the advanced search area in each database. 527 articles were identified at this initial search phase. The researcher then read the abstract of all the articles and excluded those not meeting the inclusion criteria. 465 articles were removed at this Screen phase. After removing the duplicate articles, 40 primary articles remain in the set for appraise and synthesis. Figure 2.1 displays the number of articles included and excluded at each phase.

Step 5 & 6: Appraisal and Synthesis

During these steps, the researcher further screened the articles by reading the full text and abstracted important details from each article. 25 articles were finally included in this review. The results of the abstracting process were then summarized into a table (see Appendix A). This mapping step would "produce a useful product in its own right to describe what research has been undertaken in a field and so can inform policies for future research" (Gough, 2004, p. 56). With the organized information, the research conducted critique within and across studies. The findings are presented in the following section.

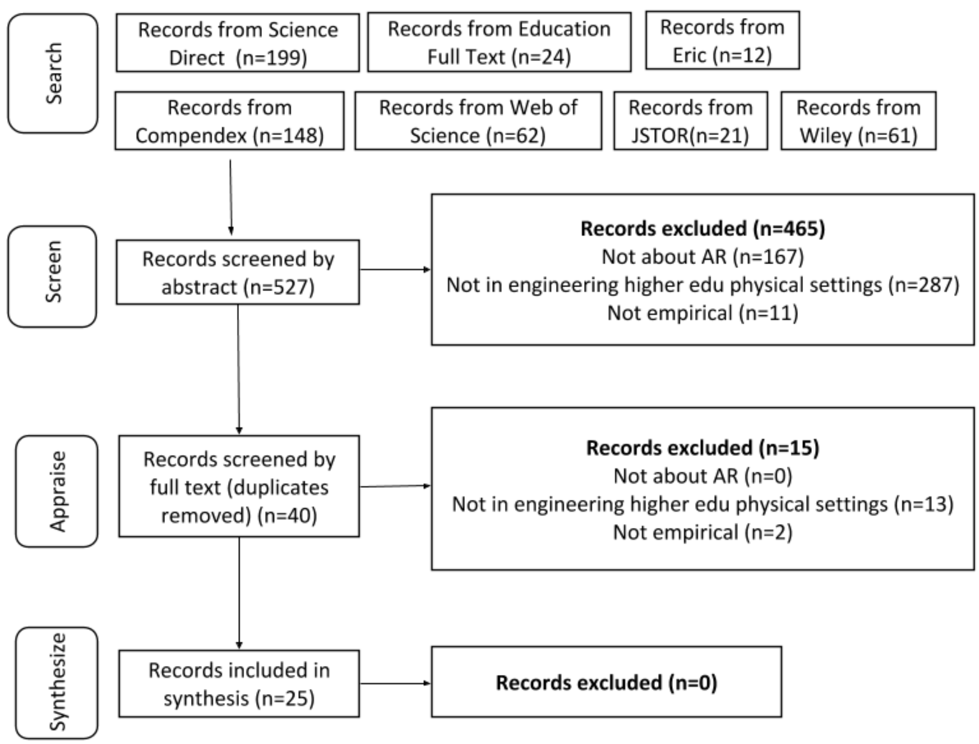

Figure 2. 1 *Article selection process, adapted from PRISMA (Liberati et al., 2009)*

Findings and Discussions

25 articles were selected following the 6 review steps described above. A summary of the key information for all the selected articles can be found in Appendix A. In this section, the results of the systematic review are presented and discussed. The findings are organized by the subcategory of the review questions to ensure each research question would be addressed in this review study.

1.1 Research Trends of AR

Figure 2.2 displays the publication trend of journal articles investigating AR in engineering education from 2007 to 2017. The overall publication trend is increasing during the past 10 years with a slight fluctuation. Specifically, no article or only one article were published each year from 2007 to 2011; while, averagely 4 articles were published each year from 2012 to 2017. This trend indicates that AR has appealed more attention from engineering researchers over the last 10 years. However, the scope of literature is still limited. Bacca et al. (2014) also reported in a systematic review study that AR is less explored in “engineering, manufacturing and construction” education (15.6%) compared to “Science” (40.6%) and “Human & Arts” (21,9%) education. They suggested that AR is popular in science education because it is effective for teaching abstract or complex concepts and allow students to visualize things that are not possible to be seen without a specialized device. AR has also been widely used in language learning and painting appreciation due to its capability to provide contextual experiences (Bacca et al., 2014). Despite the promising potential of AR in teaching abstract concepts and delivering contextual information, the integration of such technologies into teaching in engineering education is limited. Therefore, more research investigating AR in engineering education need to be undertaken.

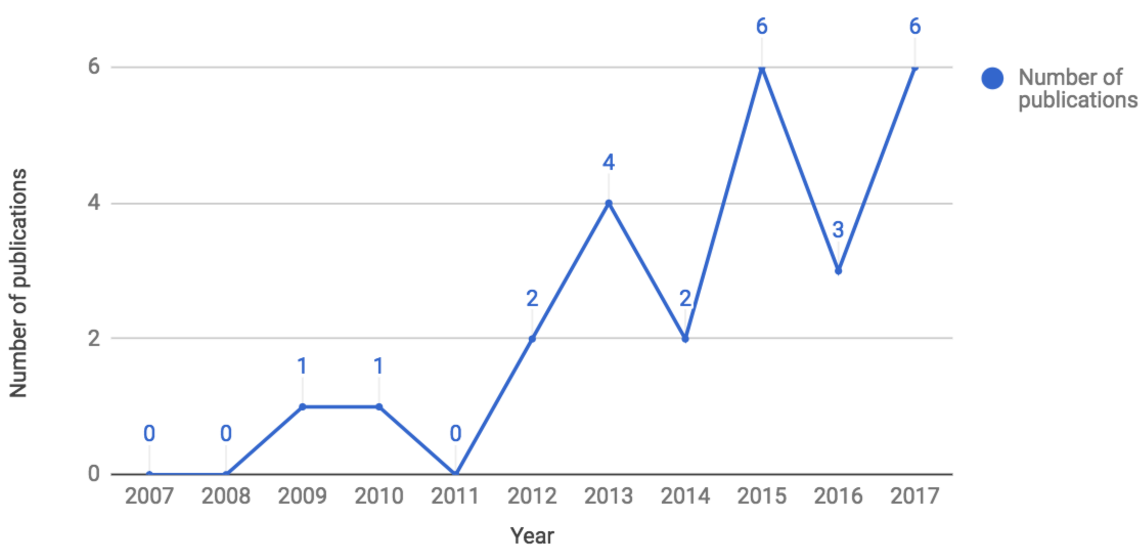

Figure 2. 2. Number of studies published in each year from 2007-2017

1.2 Distribution of Engineering Programs

Engineering is a broad academic domain which includes a variety of specializations. Thus, it is necessary to examine the distribution of publications in various engineering fields.

Table 2.1 displays the studies categorized by the engineering programs that they were carried out. Some of the studies were carried out in more than one engineering programs or recruited students from multiple engineering programs. Thus, one study can fall into more than one category.

Table 2. 1

Studies by Engineering Programs

Engineering Programs	**Studies**
Mechanical Engineering; Mechatronics engineering	Alvarez, et al. (2017); Fiorentino, Monno & Uva (2009); Frank & Kapila (2017); Martín-Gutiérrez, Contero, & Alcañiz (2015); Martín-Gutiérrez et al. (2010); Martin Gutierrez & Meneses Fernandez (2014); [Mechatronics engineering] Monroy Reyes et al. (2016)
Electronic Engineering;	Bendicho et al. (2017); Martín-Gutiérrez et al. (2015); Martin-Gutierrez, Guinters, & Perez-Lopez (2012); Riera, Redondo, & Fonseca. (2015).
Architectural Engineering; Architectural and Building Engineering	Ayer et al. (2016); Fonseca et al. (2014); Redondo et al. (2013); Riera, Redondo, & Fonseca. (2015)
Civil Engineering	Ayer et al. (2016); Shirazi & Behzadan (2014); Shirazi & Behzadan (2015); Turkan et al (2017)
Construction and Civil Engineering; Construction Engineering	Shirazi & Behzadan (2014); Shirazi & Behzadan (2015); Turkan et al. (2017); [Construction Engineering] Shanbari et al. (2016);
Industry and Civil Engineering	Dominguez et al. (2012); Martín-Gutiérrez et al. (2013a);
Industrial Engineering	Alvarez, et al. (2017); Ramírez Juidías et al. (2017)
Chemical Engineering	Bendicho et al. (2017);
Agricultural Engineering	Martín-Gutiérrez, Contero, & Alcañiz (2015)
Aerospace Engineering	Frank & Kapila (2017)
Multimedia Engineering	Fonseca et al. (2015)
Automation Engineering	Calderón & Arbesú (2015);
Engineering in general	Carbonell Carrera & Bermejo Asensio (2017); Martín-Gutierrez et al. (2013b)

Note: one article may fall into more than one categories.

Mechanical Engineering is the most popular engineering field where AR research have been performed. In Mechanical Engineering, AR tools have been used to practice technical drawing (Alvarez, et al., 2017); explain the contents of standard mechanical elements (Martin Gutierrez & Meneses Fernandez, 2014), visualize in-time dynamic stress distribution under boundary conditions (Fiorentino, Monno & Uva, 2009); develop spatial skills through observing 3D objects (Martín-Gutiérrez et al., 2010); and guide inexperienced users in machinery handling (Monroy Reyes et al., 2016). The curriculum of Mechanical Engineering requires students to "model, analyze, design, and realize physical systems, components or processes" (ABET, 2017). The popular of AR in in this engineering field may result from AR's potential in objects modeling (translating machinery sketches to 3D models) and skills training (machinery operations) (Yuen et al., 2011). AR has also been relatively often applied in Electronic, Architectural, Construction and Civil Engineering Education. These engineering fields, in common, involve sketching, modeling, designing and realizing physical 3D objects (e.g. buildings, complex electrical devices). Therefore, other engineering fields with similar curriculum requirements are more likely to benefit from incorporating AR into lessons.

2.1 Data Collection Methods

In the review, 20 out of 25 articles are quantitative research studies and the other five utilized mixed methods. The researchers have adopted a number of data collection methods and instruments. The quantitative methods include knowledge tests, skill measurements, course performances (exams, assignments, projects, design documents), class attendance, and tasks completion rate, as well as surveys and system log data (e.g. remaining time to assignment deadline). The qualitative methods include interview (Ayer et al., 2016), observation (Shirazi & Behzadan, 2015), qualitative tests (Fonseca et al., 2015; Fiorentino, Monno, & Uva, 2009), and open-ended questions in a survey (Turkan et al., 2017). The information about specific data collection method and instruments used for each study is listed in Appendix A.

Quantitative design fits well to the research in which trends or explanations need to be made (Creswell, 2011). However, this research design is weak in obtaining a deep understanding of the context and participants' perceptions. Qualitative methods could offset the weakness of qualitative research and help to answer for example following research questions: How do students perceive their learning experiences with AR in engineering classrooms (method: student interview or focus group)? How does an AR application support students collaboration in a problem-solving/ building design activity (method: observation)? Therefore, further studies which adopt qualitative or mixed-methods designs are suggested.

2.2 Evaluation Type

Another way to classify the evaluation approach is based on the evaluation type. This review study categorized the studies into overall two types: studies examining the learning effectiveness of AR and studies examining the user experiences with AR applications. The learning effectiveness were examined through measuring student performance. User experiences include aspects of satisfaction, motivation, enjoyment, usability, etc. Table 2.2 summarizes the studies based on the evaluation type and the data collection methods. Since many studies examined both learning effectiveness and user experiences, another subcategory was included in the table to highlight these studies.

Table 2. 2

Studies by Evaluation Type

Evaluation Type	Data collection methods	Studies
Educational effectiveness	Quantitative	Bendicho et al. (2017); Carbonell Carrera & Bermejo Asensio (2017); Martin-Gutierrez, et al. (2012); Martín-Gutiérrez et al. (2013a); Martín-Gutierrez, et al. (2013b); Shirazi & Behzadan (2015); Shanbari et al. (2016)
	Qualitative	Shirazi & Behzadan (2015)
User experiences	Quantitative	Calderón & Arbesú (2015); Dominguez et al. (2012); Fiorentino et al. (2009); Fonseca et al. (2015); Martin-Gutierrez, et al. (2012); Monroy Reyes et al. (2016); Ramírez Juidías et al. (2017); Redondo et al. (2013); Riera et al. (2015)
	Qualitative	Calderón & Arbesú (2015; Fonseca et al. (2015)
Educational effectiveness & User experiences	Quantitative	Alvarez, et al. (2017); Ayer et al. (2016); Fonseca et al. (2014); Frank & Kapila (2017); Martín-Gutiérrez et al. (2010); Martin Gutierrez & Meneses Fernandez (2014); Martín-Gutiérrez, et al. (2015); Shirazi & Behzadan (2014); Turkan et al. (2017)
	Qualitative	Ayer et al. (2016); Turkan et al. (2017)

Note. Several studies measure both student performance and experiences and thus fall into two categories.

Educational effectiveness. Many researchers were interested in the educational effectiveness of using AR in engineering education such as the effectiveness in improving academic performance or increasing engagement and motivation. The educational effectiveness is often examined through measuring student performance. Student performance can be measured in terms of quality, quantity, or timeliness of tasks completion. Specifically in this review study, the examples of student performance include such as knowledge tests (Frank & Kapila, 2017; Martin Gutierrez & Meneses Fernandez, 2014; Shanbari et al., 2016; Turkan et al., 2017), practical activity performance (Ayer et al., 2016; Fonseca et al., 2014; Shirazi & Behzadan (2015), spatial skill measurements (Carbonell Carrera & Bermejo Asensio, 2017; Martín-Gutiérrez, et al., 2015), class attendance (Alvarez, et al., 2017); number of student completing tasks (Martin-Gutierrez, et al., 2012), rate of practical work delivered (Alvarez, et al., 2017), and remaining time to task deadline (Bendicho et al., 2017).

To provide further evidence on the educational effectiveness of AR in engineering education, the majority of such studies made efforts to design an experiment by using a control group. Based on the nature of the treatments received by a control group, a few types of comparison were identified and listed in Table 2.3. The overall results for each type are also displayed in the table. The most common non-AR treatments received by the control group are traditional instruction methods/materials such as blackboard (Alvarez et al., 2017), blank sheets of paper for design activity (Ayer et al., 2016), traditional print manual in building design activity (Shirazi & Behzadan, 2015) and traditional class notes (Martin Gutierrez & Meneses Fernandez, 2014). The non-AR treatments also include other technologies such VR and PDF3D (Dominguez et al., 2012; Martín-Gutiérrez et al., 2013a). Some other researchers developed independent training or workshop with AR for developing student's spatial skills and were interested in the effectiveness of the AR activity. Four such studies compared student spatial skills between students who took a spatial training with AR and students who did not undergo the spatial training (e.g. Martín-Gutiérrez et al., 2010). There is also one article comparing students' academic performance when using different AR display devices: tablet PC and head mounted display (Martin-Gutierrez et al., 2012).

Table 2. 3

Studies by Type of Comparisons (Treatment Received by Control Group)

Comparison type	**Studies**	**Results**
AR versus non-AR (conventional instruction)	Alvarez, et al. (2017); Ayer et al. (2016); Bendicho et al. (2017); Gutiérrez, Contero, & Alcañiz (2015); Martín-Gutiérrez et al. (2015); Martin Gutierrez & Meneses Fernandez (2014); Ramírez Juidías et al. (2017); Redondo et al. (2013); Shanbari et al. (2016); Shirazi & Behzadan (2014); Shirazi & Behzadan (2015); Turkan et al. (2017)	Most studies reported that AR is more effective than traditional instruction to improve learning outcome, develop spatial skills, increase motivation, and reduce academic procrastination.
AR versus non-AR (other technologies)	Dominguez et al. (2012); Martín-Gutiérrez et al. (2013a);	Students used AR showed higher level of satisfaction and slightly higher spatial skill performance than other technologies
AR training versus no-training	Carbonell Carrera & Bermejo Asensio (2017); Martín-Gutiérrez, Contero, & Alcañiz (2015); Martín-Gutiérrez et al. (2010) Martín-Gutierrez et al. (2013b)	Students who took the AR training significantly improve their spatial skills than those who didn't take trainings.

Note. One article may fall into two categories (e.g. Martín-Gutiérrez et al., 2013a has multiple treatments)

User Experiences. Another evaluation type identified in this review is evaluation of user experiences, in which student's perceptions and attitudes toward the use of AR were obtained. Utilizing a survey has been the most common approach to gather information about student's experiences (19 out of 25 articles). Survey has been used to measure several aspects of student perceptions such as overall satisfaction (Dominguez et al., 2012; Martin-Gutierrez, et al., 2012; Martín-Gutiérrez, et al., 2015), motivation (Alvarez, et al., 2017; Shirazi & Behzadan, 2014), usefulness (Ramírez Juidías et al., 2017; Riera, et al., 2015; Turkan et al., 2017), enjoyment (Martin-Gutierrez, et al., 2012; Shirazi & Behzadan, 2014; Turkan et al., 2017), and usability (Fiorentino, et al., 2009; Fonseca et al., 2014; Redondo et al., 2013). Qualitative methods used in the studies to obtain information about students' experiences include focus group interview (Ayer et al., 2016) and qualitative usability test (UX techniques) (Fonseca et al., 2015).

3.1 Reported Benefits of AR

The results of this review study reveal that using AR in engineering education provided various benefits for students and instructors. The benefits are reported in Table 2.5 and discussed in the following paragraphs.

Table 2. 4

Reported Benefits of AR in Engineering Education

Benefits	**Studies**
Increase engagement and motivation	Fonseca et al. (2015); Alvarez, et al. (2017); Calderón & Arbesú (2015); Fiorentino et al. (2009); Fonseca et al. (2014); Martin Gutierrez & Meneses Fernandez (2014); Martín-Gutiérrez et al. (2015); Shirazi & Behzadan (2014); Shirazi & Behzadan (2015)
Develop spatial skills	Carbonell Carrera & Bermejo Asensio (2017); Fonseca et al. (2014); Martín-Gutiérrez et al. (2010); Martín-Gutiérrez et al., (2015); Martín-Gutiérrez et al. (2013a); Martín-Gutiérrez et al. (2013b); Redondo et al. (2013)
Enhance knowledge understanding	Fiorentino et al. (2009); Frank & Kapila (2017); Martin Gutierrez & Meneses Fernandez (2014); Shanbari et al. (2016); Shirazi & Behzadan (2014)
Improve practical performance	Ayer et al. (2016); Fonseca et al. (2014); Shirazi & Behzadan (2015)
Support autonomous learning & save instructor's time	Martín-Gutiérrez et al. (2015); Martín-Gutiérrez et al. (2012); Shirazi & Behzadan (2015)
Reduce equipment cost	Fiorentino, Monno & Uva (2009); Frank & Kapila (2017); Martín-Gutiérrez et al. (2010)
Reduce academic procrastination	Bendicho et al. (2017)

Note. One article may fall into multiple categories.

Increase motivation and engagement. The top benefit of AR in engineering education reported in the reviewed articles is increasing students' engagement and motivation. For instance, Calderón and Arbesú (2015) incorporated AR technology into their lab experiments and observed that all the students "centered their attention to the practice" (p. 126). The survey results in six articles also confirmed that AR could be used to create motivational, engaging and interesting learning experiences (Fonseca et al., 2014; Shirazi & Behzadan, 2014; Martin

Gutierrez & Meneses Fernandez, 2014; Alvarez, et al., 2017; Fonseca et al., 2015; and Fiorentino et al., 2009). Particularly, the use of AR also encouraged student-student collaboration and increased frequency of students ‘communications (Martín-Gutiérrez et al., 2015; Shirazi & Behzadan, 2015).

Develop spatial skills. Another notable benefit of AR reported (in six articles) is spatial skills development. Spatial skill refers to the “ability to picture three-dimensional (3D) shapes mentally” (Martín-Gutiérrez et al., 2010). This ability is critical in engineering education because engineering students are all expected to be able to sketch and design real 3D object (e.g. a building) through two-dimensional methods (Dominguez et al., 2012). In this review, three studies reported that students who used AR treatments improved more spatial skills compared to students who worked with non-AR treatments such as 2D representation (Carbonell Carrera & Bermejo Asensio, 2017), traditional lectures (Redondo et al., 2013), or VR or PDF3D (Martín-Gutiérrez et al., 2013a). It is also reported that AR could be used to develop effective trainings or workshops to help students develop spatial skills (Martín-Gutiérrez et al., 2010; Martín-Gutierrez, et al., 2013b; Martín-Gutiérrez et al., 2015). However, in Ramírez Juidías et al. (2017) where 2D, 3D and AR objects were presented as paired comparisons during a visualization activity, the students did not recognize the usefulness of AR for better visual understanding in addition to 2D and 3D objects. It would be worth investigating whether any specific feature of an AR tool afford the spatial skill development such as 3D visualization.

Enhance knowledge understanding. Five articles (20%) reported that the use of AR could enhance students’ understanding of abstract engineering concepts. For instance, Martin Gutierrez & Meneses Fernandez (2014) developed an augmented book, L-ELIRA, to help mechanical engineering students to learn mechanical elements (e.g. Bearings, Gears and Spring).

Through capturing the marker on the physical book, the AR tool provides visualization of 3D standard element from any point of view. The students who used L-ELIRA demonstrated statistically significant better exam performance compared to the students who used traditional class notes to learn the concepts. Shanbari et al. (2016) also reported that the use of augmentation video to supplement traditional lectures increased students' understanding and identification of brick veneer wall elements and roof elements in assembly tests. These studies proved that pedagogical tools involving AR technology have potential to effectively supplement the traditional lectures or textbooks and to enhance students' understanding of engineering concepts. However, one article in this review reported that no significant difference was identified in knowledge test scores between students who used an AR tool and traditional textbook learning, which indicates the use of AR tool did not holistically improve student learning outcomes compared to textbook learning (Turkan et al., 2017).

Improve practical performance. In addition to teaching conceptual knowledge, AR can also be used to develop useful tools for teaching practical or procedural knowledge such as machine operation and engineering experiments. Three studies (12%) reported that the use of AR applications helped students to improve performance in practical tasks. For instance, engineering students who completed a design activity with an AR–based educational game demonstrated better performance in terms of considering more design concepts and more possible building materials in their designs compared with the students who used paper-based versions of materials (Ayer et al., 2016). In another study, civil and construction engineering students who used the AR for content delivery performed better in a building design activity with respect to building volume, number of elements, and completion time (Shirazi & Behzadan, 2015).

Support autonomous learning. Three articles found that AR supported students' autonomous learning. Autonomous learning describes the behaviors of learning which is intrinsically motivated and internally regulated (Black & Deci, 2000). In autonomy-supportive educational context, students are more likely to feel sense of control and perform with interest or personal importance. In contrast, in controlling context, student's behaviors are regulated by external contingencies or introjected demands (Black & Deci, 2000). An example of autonomy-supportive activity can be providing students with necessary information while encouraging them to solve a problem in their own way with the information (Black & Deci, 2000). In Martin-Gutierrez et al. (2012), an AR app was used as an alternative to traditional script manual to instruct students to perform operations over the electric machines. The study found that most students were able to perform the operations properly without teacher assistance. Similarly, in an electrical machines course, students were able to use a set of AR apps to learn theoretical concepts on their own pace and collaborated with other students in laboratory practices (Martín-Gutiérrez et al., 2015). In Shirazi & Behzadan (2015), students used AR to receive instructions from a virtual avatar and independently completed building design and assembly activity. In all of these cases, the students were given opportunities to take control of their learning and complete tasks at their own pace and path with AR apps. This is one of the significant potential of AR in education, as reported in Yuen et al. (2011).

Save teacher's time and equipment cost. As mentioned above, with AR tools, students were able to autonomously learn knowledge and perform experiments without teacher assistance. This could eliminate the constant presence of a teacher and thus reduce instructors' time investment in class management and also repeated explanations. AR tools which incorporate AR technology with real laboratory devices can also be used as cost-effective approaches to enhance hands-on laboratory. AR requires "simple and cheap hardware setup" compared to expensive laboratory equipment (Martín-Gutiérrez et al., 2010, p 90). Frank and Kapila (2017) also predicted that, with the portable AR devices, students in future would be able to perform experiments out of the laboratory, which would increase accessibility and eliminate expenses of laboratories.

3.2 Reported Challenges of AR

Table 2. 5

Reported Challenges of AR in Engineering Education

Challenges	**Studies**
Student's unfamiliarity to AR technology or using mobile devices for learning	Shirazi & Behzadan (2015); Fonseca et al. (2015); Turkan et al. (2017)
Usability issue with display devices	Turkan et al. (2017); Monroy Reyes et al. (2016)
Knowledge and time required from teachers to design AR contents	Monroy Reyes et al. (2016)

Although AR affords a number of benefits, it also brings challenges for both instructors and students. For students, although many studies reported students' positive attitudes and good acceptance of tools with AR technology (Calderón & Arbesú, 2015; Martin-Gutierrez, Guinters, & Perez-Lopez, 2012), the unfamiliarity with AR technology may cause frustration in students and also require extra time from students to familiarize with the new technology (Shirazi & Behzadan, 2015). Furthermore, when using mobile AR applications, some students have limited experience of using mobile devices for educational purpose (Fonseca et al., 2015), which may also result in unfamiliarity and frustration. Being aware of this, Alvarez, et al. (2017) included a preliminary step in their study to make students familiar with the AR tool before asking them to perform tasks with the tool. Turkan et al. (2017) also suggested providing students with guidance to navigate the AR applications to reduce frustration and the time for learning how to use AR tools.

Another challenge is related to the display devices used for AR. In Turkan et al. (2017), the students needed to hold up the tablet to capture the marker via the tablet's camera while interacting with the tablet screen. The students found it difficult to maintain the position while interacting with the app through clicking or sliding actions. Monroy Reyes et al. (2016) also mentioned this limitation that when using smartphone as display devices, student will have at least one hand busy manipulating the device. Turkan et al. (2017) proposed to add a function in the future allowing students to freeze the AR image and interact with the still image. Drawbacks were also detected for using AR glasses as display devices. In Monroy Reyes et al. (2016), some students showed visual tiredness and had problems with focusing after a short period of time when wearing the AR glasses.

From instructors' perspectives, the challenges reported focus on the difficulty in implementing AR tools in curriculum. The design of AR contents and implementation of AR into lessons requires different sets of knowledge such as programming, design, and AR (Monroy Reyes et al., 2016). This challenge was also revealed in other studies about AR in education in general. For instance, Yuen et al. (2011) reported that creating and deploying AR content is still quite difficult for teachers and students because it requires significant technical knowledge. They also suggested that easier-to-use development kits would be a potential solution to solve the problem in the future.

Overall, both technical and pedagogical challenges have been revealed from previous studies in engineering education. Although some potential solutions were proposed, there are still many problems and challenges to overcome in order to maximize the benefits of AR technology in engineering education. Educators and researchers should keep up with the advance of AR technology and continuously explore approaches to address the challenges through research efforts.

Summary

A systematic review of articles on the use of AR in engineering education was conducted and reported in this chapter. A total of 25 articles were identified and analyzed following Borrego, Foster, and Froyd's (2014) systematic review procedure. The results of this review study were described and discussed in the previous section and the following categories were addressed: publication trend during the past ten years, distribution of articles by engineering programs, data collection methods, evaluation type, reported benefits and challenges of using AR in engineering education. This section will present a short summary of the main findings and suggestions for future research directions.

The number of published studies about AR in engineering education has slightly increased during the past 10 years, which indicates that AR has appealed more attention from engineering researchers. Studies have been carried out in some of the engineering programs including (ordered from more to less articles) Mechanical Engineering, Construction Engineering, Architectural Engineering, Electrical, Computer, Communication and Telecommunication Engineering, Civil Engineering, Industrial Engineering, and Agricultural Engineering, Manufacturing Engineering, Surveying Engineering, and Aerospace Engineering. The findings indicate that the scope of literature is still limited in terms of the total number of studies and the range of engineering programs in which AR studies have been carried out. Therefore, more research investigating AR in engineering education need to be undertaken and also to cover a wide range of engineering programs.

Regarding evaluation approach, 20 out of 25 studies are quantitative research and the other five are mix-method studies. The data collection methods that have been used are listed in Table 2.6. Future research adopting qualitative data collection methods is suggested to obtain a deep understanding of the context and participants' perceptions. Based on the objects evaluated, studies can also be categorized into two types: studies measuring learning effectiveness and user experiences of using AR in engineering education. Around one third of the studies measured both aspects. The studies evaluating learning effectiveness have conducted comparisons of AR versus non-AR treatments, AR versus no-treatment, and AR different devices. User experiences include aspects of usability, satisfaction, motivation, usefulness, and enjoyment.

Table 2. 6

Summary of Data Collection Methods and Instruments

	Learning Effectiveness	**User Experiences**
Quantitative	knowledge tests, skill measurements, course performances (exams, assignments, projects, design documents), class attendance, and tasks completion rate, system log data	Surveys
Qualitative	Observation	Interview, qualitative usability test, open-ended questions in survey

The benefits for AR in engineering education are (ordered by number of articles from more to less) increasing student engagement and motivation, developing spatial skills, enhancing knowledge understanding, improving practical performance, supporting autonomous learning, reducing equipment cost, and reducing academic procrastination. AR has vast potentials in enhancing teaching and learning in engineering education. Researchers should continue exploring and verifying the affordances of AR technology in engineering classrooms or laboratories.

The challenges reported include student's frustrations in using AR applications resulted from unfamiliarity with AR technology or using mobile phone/tablet for educational purpose; usability issues of AR display devices; and instructor's difficulty in designing and implementing AR contents into traditional curriculum. More practices and research are needed to explore approaches to address the reported challenges of using AR in engineering education such as how to support instructor in designing and implementing AR contents into traditional lessons; and how to facilitate AR activities to ensure smooth user experiences.

CHAPTER 3. METHODOLOGY

This research study was designed to investigate the learning effectiveness of augmented reality in teaching structural analysis and obtain student's perceptions of using augmented reality to learn structural analysis concepts. The study was guided by the following research questions:

1. Does a pedagogical approach involving AR technology improve student's learning outcomes compared to traditional lecture-based approach in teaching structural analysis？
2. What are students' perceptions of using an AR application in learning structural analysis concepts?

To answer the research questions, a self-developed AR application was piloted in a structural analysis course. A quasi-experiment quantitative-method research design was followed in this pilot study. The data sources include pretest, posttest, and a survey.

Research Context

The pilot study was carried out in Structural Analysis (CE 332). It is a three-credit core course in the Civil Engineering curriculum in the Department of Civil, Construction and Environmental Engineering (CCEE) at Iowa State University (ISU). Structural Analysis is an introductory course in structural engineering and also a prerequisite for several other design courses in the program including Structural Steel Design, Reinforced Concrete Design, and Capstone Design project. In this course, students learn to analyze forces and displacements in determinate and indeterminate structures using both equilibrium and energy-based solutions. This course is offered during all semesters and the target students are junior or senior students. The course had two sections and totally 106 students were enrolled in this course during spring 2018 semester.

Design of the Augmented Reality Application

To help students to visualize the structural behaviors as well as linking structural representations with physical structures, a mobile AR application, iStructAR, was developed by engineering educators in the CCEE department of ISU. The AR system consists of five tasks, each focusing on a different specific concept in structural analysis. The first task was examined in this study. Through the application, a real campus building (a skywalk) is superimposed with a virtual representation of the structure to demonstrate the concept of simply-supported beams.

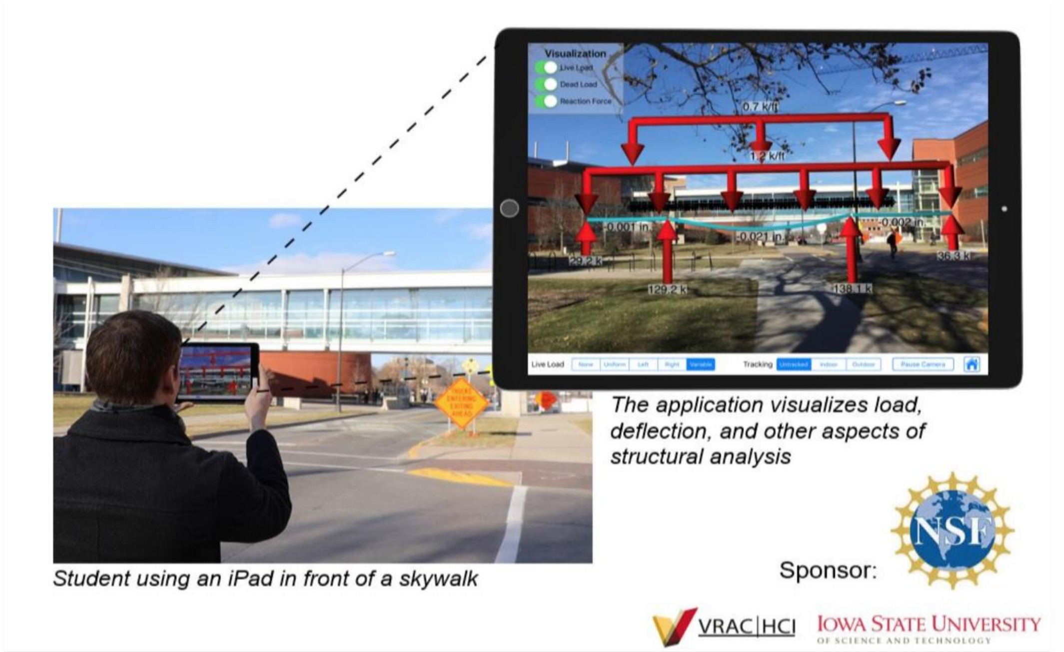

Figure 3. 1. Student uses "outdoor" tracking mode to view loading on campus Skywalk

The application supports real-time tracking of printed photograph for indoor use and near real-time tracking of the same outdoor structure in various weather conditions. The application was developed for iOS systems and can be installed in iPads. When the structure is tracked through the device's built-in camera, the virtual representation will be superimposed on the structure. Figure 3.1 shows how the application surface looks like when a student holding up an iPad in front of the Skywalk building.

As shown in Figure 3.2, the system highlights the virtual beam indicating all the loads on the beam so that students can better understand how the loads are transferred to the beam from other structural components, building materials or people on the structure. The application also allows students to adjust the distributed load forces while observing the reaction forces location and magnitude and; the deflection shape of simply supported beam through the graphical representation of the building. Students can change the load by either clicking live load preset buttons or draging-and-droping the lines on the screen. Considering that it is not convenient to interact with the app while holding the devices, the system also allows students to pause the camera and interact with the saved still picture.

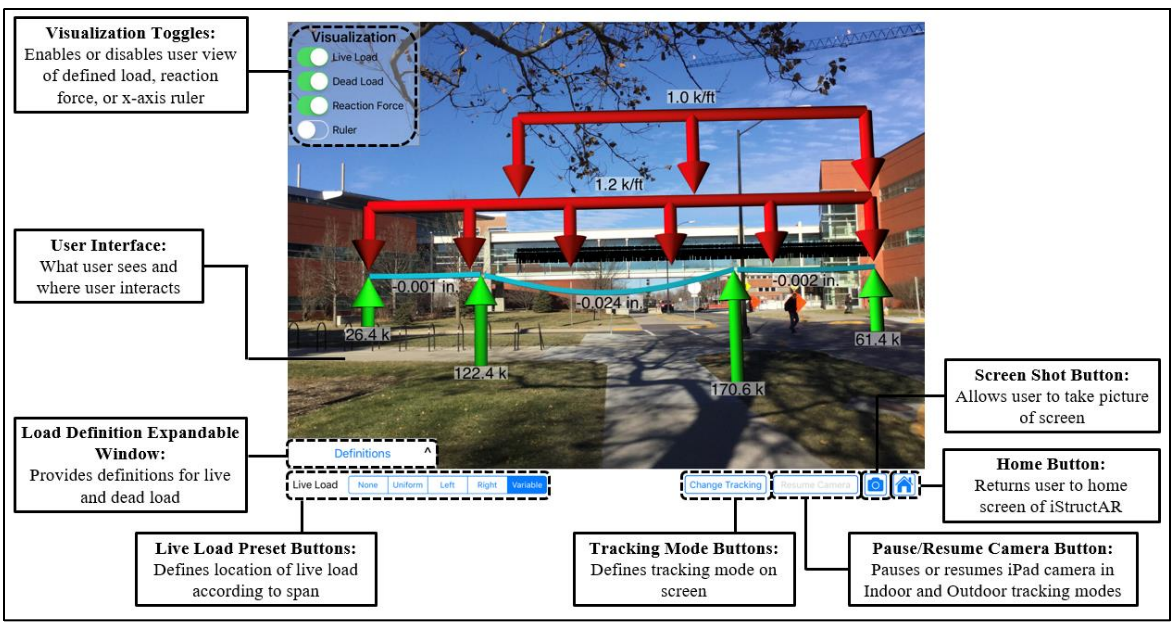

Figure 3. 2. Interface of iStructAR

Design of the Experiment

A quasi-experimental design procedure was followed to investigate the learning effectiveness of using an AR application to teach structural analysis. Quasi-experiments refer to the experimental designs that do not involve random assignment (Gall, Borg, & Gall, 2002, p. 402). This type of research design is commonly used when random assignment of participants to treatment conditions is not possible (Gall et al., 2002, p. 401). In this study, all students in one course section must be given the same treatment, which did not allow random assignment. Except for the random assignment of participants, this study followed the same steps with experimental design. Two sections randomly served as control and experimental group. Both groups took a pretest before the treatment (AR activity) and a posttest after the treatment, which follows a nonequivalent control-group design (Gall et al., 2000, p. 402). Figure 3.3 displays the design of the experiment.

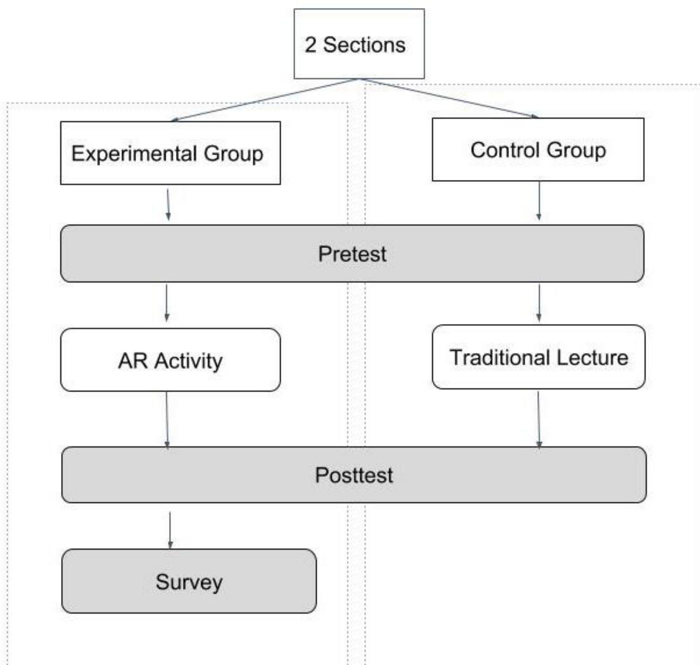

Figure 3. 3. Flowchart of the Quasi-Experimental Design

The experiment was implemented in fifth week of the semester to fit in the existing curriculum and lasted two 50-minutes class periods (Wednesday and Friday). In order to conduct the pilot study, the two class periods were borrowed and taught by another instructor who was in the same program and familiar with the AR application. The students in the control group attended regular lectures during both class periods; while the AR group participated in an AR activity. The concepts explained by the instructor in both sections were identical.

AR activity. An AR activity was implemented in the experimental group as an alternative pedagogical approach to lecture-based instruction. To familiarize the students with the AR application, the instructor first projected an iPad screen to a large whiteboard and demonstrated how to interact with the application interface (see Figure 3.4). The students then worked in small groups and used the AR application to solve a few problems on an exercise handout. The AR activity was initially designed for outdoor environment in which students could stand in front of the physical building. However, in this pilot study, considering the weather condition and the difficulty to manage around 40 students outside, the activity was carried out in a regular classroom setting where the students used indoor tracking mode of the application to observe a printed picture of the building on the wall (see Figure 3.5). Students were give opportunities to use the application outdoor between the two class periods. During the second class period, the students reflected on their observations and listened to instructor's explanations. The detailed lesson plan for this AR activity was included in Appendix B.

Figure 3. 4. Instructor Demonstrating the Use of iStructAR

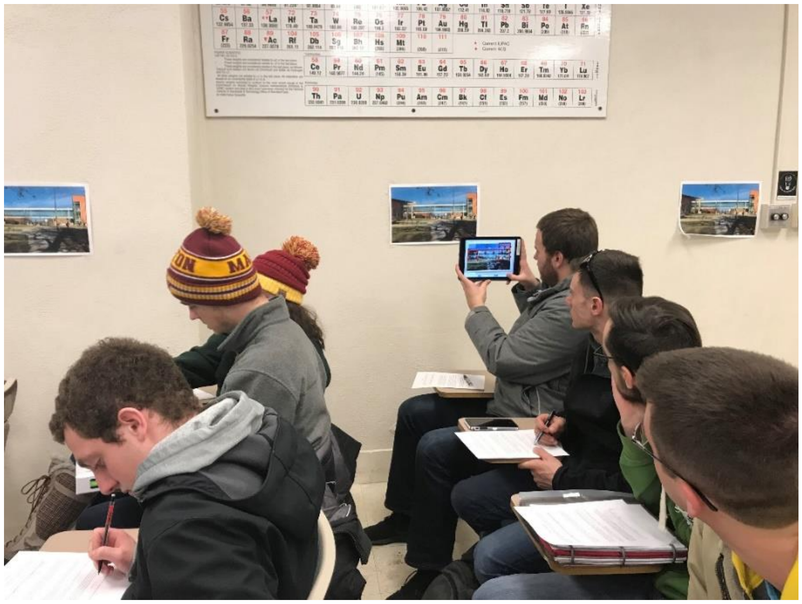

Figure 3. 5. Students Working with iStructAR

Participants

This study was piloted in a structural analysis course (CE 332) and performed during spring 2018 semester. A total of 106 students enrolled in the course. Out of the entire student population, only students who took both the pretest and posttest were included in the quasi-experimental design for measuring the learning effectiveness of AR. The survey participants were the students who attended class during the pilot study and had interactions with the AR application. Table 3.1 displays the number of participants included for the study. Regarding the survey responders' prior experiences with using iPad and AR, around half of the students (18/45) own iPad and eleven of them have used iPads for study purposes. Nine students reported that they have used another AR application before.

Table 3. 1

Number of Participants in the Study

Course Section	Entire Population	Pretest & Posttest	Survey
Control	47	30	/
Experimental	59	37	45

Research Instruments

Knowledge Tests

To compare the learning gains between experimental and control group, both groups were asked to take a pretest and a posttest. The pretest and posttest were developed by the instructor to measure the knowledge acquisition of students during the two sections. The test questions were reviewed by another subject matter expert before being used to assess the validity of the test instruments. The tests consisted of three questions which covered three different concepts including load type, deflection, and reaction force. The pretest and posttest were slightly different in order to avoid learning by mimicry. However, at the same time, they were very similar to ensure that the same set of concepts would be measured. For instance, in both tests, the students were asked to label different types of loads, draw approximate deflection of the beam, and rank the supports by the magnitude of reaction forces. The only difference was that the structure had one beam and two supports in the pretest, while three beams and four supports were used in the posttest. The structure used in posttest was a little bit more complicated than the one in pretest. See Appendix C for the test questions.

Survey

To obtain students' perceptions on use of AR in learning structural analysis (research question 2), a survey (see Appendix D) was distributed to the students in the experimental group after the AR activity. The survey contains 17 questions asking about student's opinions on the AR app and 7 questions for student's background information.

The opinion questions are all multiple-choice questions which ask students to rate the helpfulness of the AR app or agreement to certain statements on a 5-point Likert scale. These questions were modified from Turkan et al. (2017) and based on the Technology Acceptance

Model (Davis, 1989). In particular, the survey measured perceived usefulness, perceived enjoyment, attitude toward using, and intention to use. The other two dimensions of the model (interface style and perceived ease of use) were excluded in this study because they were covered in a separate usability test study for the same AR app.

The background questions were designed to obtain student's basic demographic information as well as their experiences with iPad and AR technology. The demographic information of the participants helps to ensure the sample is representative of the student population of this course, which would allow the generation of the results.

Research Procedure

Participants Recruitment

The participants are students in the structural analysis course during spring 2018 semester. All students who attended the class during the experiment period were asked to take the pretest and posttest. The survey was announced in class and participation was voluntary.

To protect the human subjects involved in this research, an IRB has been submitted and approved by the Institutional Review Board of Iowa State University. The approval letter can be found in Appendix A. The research also followed the procedure required by the IRB to product the participants. For instance, the students' names on the quiz sheets were replaced with pseudo-names throughout the analysis and report stages of the study. Also, the survey is anonymous and does not reveal any identification.

Data Collection

The pretest and posttest were deployed in both sections of the course. The students were asked to take the pretest before the treatment and take the posttest after the treatment. The time interval between the two tests was one week. The surveys were printed out and distributed in class. The students volunteered to fill out the survey.

Data Analysis

Pretest and posttest. Student's responses to the quiz questions were graded on correctness and accuracy. To answer the first research question about whether the proposed pedagogical approach involving AR technology improve students learning outcomes (measured by test scores) compared to traditional lecture-based learning, both groups' pretest and posttest scores were recorded for analysis. A t-test was used in this study to test the significance of the difference between two sample means. The study first examined if students improved their test score from pretest to posttest inside each group by conducting paired samples t-test. An independent samples t-test was later performed to examine if the pretest-posttest score change was significantly difference between control and experimental group. SPSS statistics analysis software was used to perform the test analysis.

Survey. A survey was filled out by the students in the experimental group to obtain their perceptions of the AR app. Students responded to the Likert-scale questions and the responses are reported in descriptive statistics such as number and percentage.

CHAPTER 4. RESULTS

The research questions guiding this study are: (1) Does a pedagogical approach involving AR technology improve student's learning outcomes compared to traditional lecture-based approach in teaching structural analysis? and (2) What are students' perceptions of using an AR application in learning structural analysis concepts? To answer the research questions, a self-developed AR application was piloted in a Structural Analysis course. A quasi-experimental quantitative-method research design was followed in this pilot study. The data collection instruments include pretest and posttest, as well as a survey. The results of the data analysis will be described in this chapter and organized by the two research questions.

Learning Effectiveness

To answer the first research questions about whether the proposed pedagogical approach involving AR technology improves student learning outcomes (measured by test scores), as compared to traditional lecture-based learning, both groups' pretest and posttest scores were recorded for analysis. In order to calculate the score's change from pretest to posttest for each student, only the test scores of students who took both the pretest and posttest were included for data analysis (37 students in the experimental group and 30 students in the control group).

In-group Comparisons

First, the study examined the students' test score change from pretest to posttest inside each group by conducting several pairs of in-group comparisons. In-group comparisons would provide a comprehensive understanding of the dynamics of student's performance. To measure if the changes of pretest-posttest score are statistically significant, a paired samples t-test was performed. A t-test is commonly used to test the significance of differences between two sample means. When the two samples are related in some way, paired samples t-test is used. In this study, the students who took the pretest (sample 1) and the students who took the posttest (sample 2) are the same group of students. Thus, it is appropriate to use paired samples t-test.

Table 4.1 displays the score change for each group from pretest to posttest as well as the paired samples t-test results. No significant difference was found between pretest and posttest total score inside control group ($p = 0.53$) and the experimental group ($p = 0.62$). This result indicates that the students in both groups didn't significantly improve their overall test scores after the lesson. The score change for the individual sub-questions were also examined. For load type question, the mean score didn't increase in the control group, while it increased a little bit from pretest to posttest in the experimental group. However, the t-test results showed that no significant change was found in this question score for either control group ($p = 1.00$) or experimental group ($p = 0.183$). In terms of the question measuring deflection concept, both control ($p = 0.02$) and experimental group ($p = 0.00$) significantly increased the test score. It is surprising that, for reaction force question, both groups decreased their mean score and the experimental group even significantly decreased the score ($p = 0.00$).

Between-group Comparisons

To answer the first research question about whether an AR approach improve student's learning test scores compared to traditional lecture approach, the between-group comparison was conducted. As displayed in Table 4.1, the experimental group overall scored much higher on the pretest than the control group, which may result from the quasi-experiment design. To adjust for initial difference in mean pretest scores, the pretest-posttest score change instead of posttest score was regarded as the dependent variable. It is of interest that if the mean score change in control group is equivalent to the mean score change in the experimental group.

Table 4. 1

T-test Results Comparing Pretest and Posttest on Test Score for Each Group

	Pretest *M* (*SD*)	Posttest *M* (*SD*)	*Sig.*
Questions		Control (n = 30)	
Load Type	29.5(2.7)	29.5 (2.7)	1.00
Deflection	20.7 (11.1)	29.3 (13.4)	0.02*
Reaction Force	21.5 (13.5)	16 (15.2)	0.12
Total	71.7 (19.3)	74.8 (21.6)	0.53
		Experimental (n = 37)	
Load Type	28.8 (5.5)	30 (0.0)	0.183
Deflection	26.6 (12.8)	35.3 (7.5)	0.00*
Reaction Force	29.2 (4.9)	21.1 (13.9)	0.00*
Total	84.6 (16.5)	86.4 (14.6)	0.62

Note. *M* = mean. *SD* = standard deviation. The possible points for sub-questions: 30 points for load type; 40 points for deflection; 30 points for reaction force; and total is 100 points.
*$p < 0.05$.

An independent samples t-test was performed to compare the mean score change in the two independent samples: control and experimental group. In this study, the null hypothesis is that there is no difference between the mean score change of students who learn structural analysis with AR and who learn with traditional lectures, H_0: $\mu_{(control)} - \mu_{(experimental)} = 0$. The alternative hypothesis is that there is difference between the mean score change of students who learn with AR and who learn with traditional lectures: H_a: $\mu_{(control)} - \mu_{(experimental)} \neq 0$.

As displayed in Table 4.2, in terms of the total score of tests, there was not a significant difference in the score change for control group and experimental group; $t(65) = 0.24$, $p = 0.81$. Thus, the results failed to reject the null hypothesis that mean score change in control group is equal to that in experimental group. This finding indicates that the proposed pedagogical approach involving AR technology equivalently improved student learning performance (measured by test scores) to traditional lecture-based learning.

Table 4. 2

T-test Results Comparing Control and Experimental Group on Score Change

Group	*n*	*M* (*SD*)	*t*	*df*	*Sig.*
Control	30	3.17 (27.43)	0.24	65	0.82
Experimental	37	1.76 (21.42)			

Note. *M* = mean. *SD*= standard deviation.
$*p < 0.05$.

Considering that the impact of the AR approach on learning may vary with different concepts, the between-group comparison (independent samples t-test) was also performed separately for each question in the test. Table 4.3 displays the t-test results comparing control and experimental group on test score change for each individual test question. The results show that no significant difference was found in score change of control and experimental group for question measuring load type, $t(65) = -1.02$, $p = 0.31$; deflection, $t(65) = 0.00$, $p = 1.00$; or reaction force, $t(65) = 0.63$, $p = 0.53$). Therefore, it can be concluded that the effectiveness of AR approach is equivalent to traditional lecture-based approach in teaching the structural analysis concepts.

Table 4. 3

T-test Results Comparing Control and Experimental Group on Score Change for Individual Question

Question	Group	*n*	*M* (*SD*)	*t*	*df*	*Sig.*
Load Type	Control	30	0.00 (3.94)	-1.02	65	0.31
	Experimental	37	1.22 (5.45)			
Deflection	Control	30	8.67 (19.56)	0.00	49.01	1.00
	Experimental	37	8.65 (13.21)			
Reaction Force	Control	30	-5.50 (18.68)	0.63	65	0.53
	Experimental	37	-8.11 (15.25)			

Note. *M* = mean. *SD*= standard deviation.
$*p < 0.05$.

Students' Perceptions

To answer the second research questions regarding the students' perceptions of the AR application, the students in the experimental section were asked to fill out a survey. 45 students responded to the survey in the experimental group. The analysis results of the survey responses are described in this section.

Perceived Usefulness

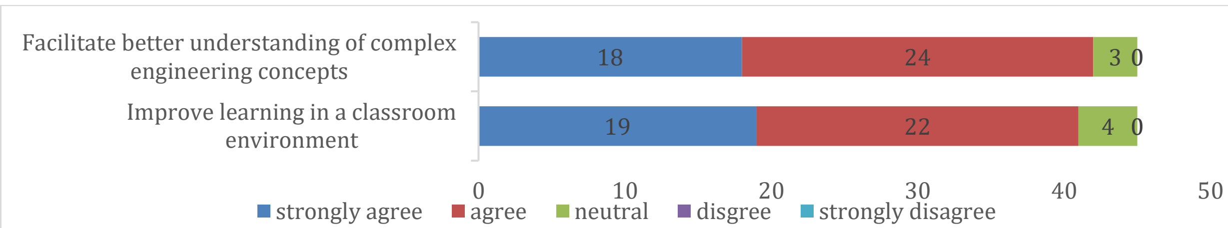

Figure 4. 1. Students' perceived overall usefulness of AR

Overall, the students held positive attitudes toward the usefulness of the AR app in learning structural analysis. As shown in Figure 4.1, the majority of students strongly agreed or agreed that the use of AR facilitated better understanding of complex engineering concepts (93%) and improved learning in a classroom environment (91%). The questionnaire also asked the students how the AR app helped them to learn specific concepts or complete tasks. Figure 4.2 displays these questions and the students' responses to the questions. Most students reported that the AR app was very helpful or helpful for them to visualize things. Specifically, a large portion of respondents indicated that AR helped them to visualize the connection between a model and the real building (96%), visualize the structural components of a building (87%), visualize the reaction of a structure caused by certain loads (84%), and visualize the deflection of a structural element under certain loads (93%). Most students also reported that the use of AR helped them to distinguish different type of loads (87%), analyze a structure (93%), and draw a deflection shape (89%). However, not all questions received very positive responses. Less than half of the students felt that the use of AR was very helpful for solving structural analysis on their own

(42%) and understanding how to calculate load (47%). While, overall these percentages are low in comparison to the results from other survey questions. This makes sense because the AR application did not instruct students how to independently solve structural analysis problems, but rather showed straightforward results when loading conditions were altered.

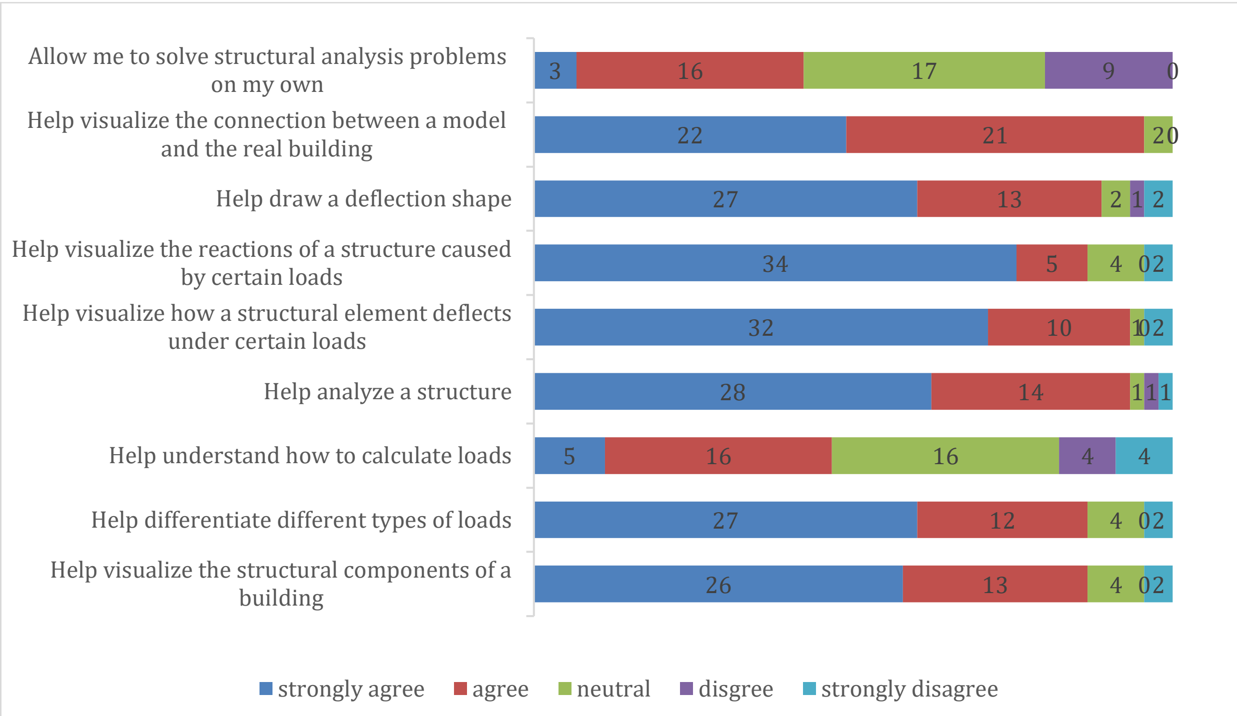

Figure 4. 2. Students' perceived helpfulness of AR to their learning specific concepts

Regarding the helpfulness of the interactive features of the AR app for students learning, the survey responses were highly positive, as shown in Figure 4.4. The majority of the students expressed that being able to manipulate the location of the load helped them understand the effect that the load locations has on structural behavior (98%) and being able to manipulate the magnitude of the load helped them understand how the load influenced the structural behavior (93%).

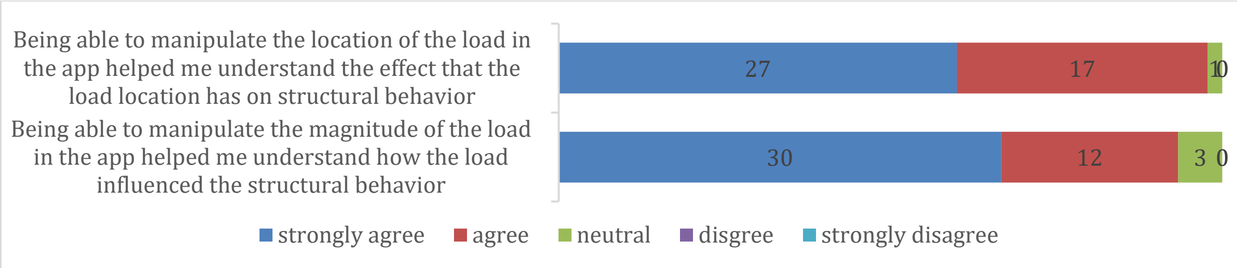

Figure 4. 3. Students' perceived usefulness of the interactive features of the AR app

Perceived Enjoyment

Figure 4.5 displays the students' responses to the questions in relation to perceived enjoyment of using the AR app. Most of the participants expressed positive opinions on the enjoyment of using AR to learn structural analysis. For instance, 93% of the respondents reported that they enjoyed using the AR app. Most students also agreed that the AR application allowed learning by playing (93%); the AR application makes learning more interesting (89%), and it was fun to see the hidden structures of a building (93%).

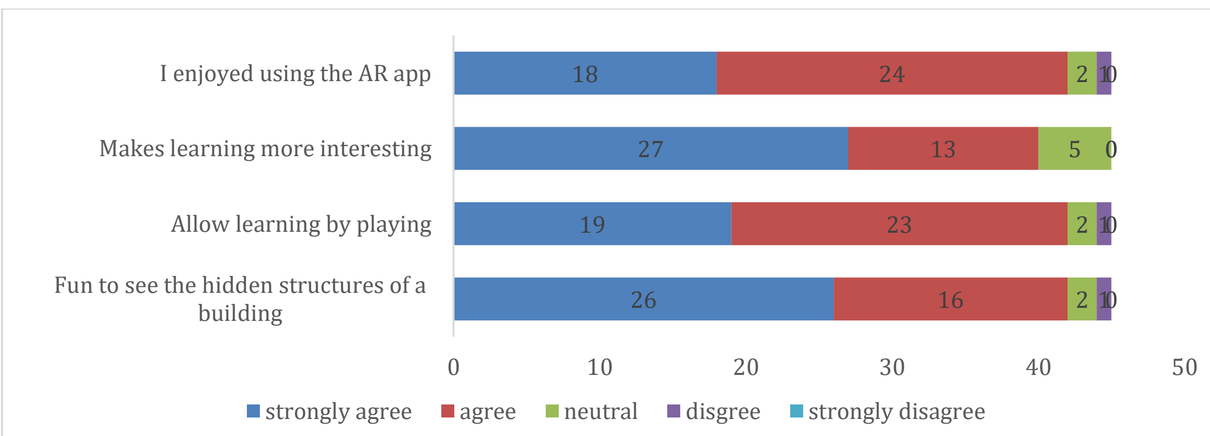

Figure 4. 4. Students' perceived enjoyment of using AR apps to learn

Attitude and Intention to Use

As shown in Figure 4.6, the majority of the students (93%) believed that using an AR app to learn structural analysis concepts is a good idea. The survey responses are also positive in relation to intention to use AR. Particularly for the AR app used in the study, 84% participants responded that they would like to use the app in the future and 87% responded they would like to recommend it to their fellow students. When it comes to a general AR app, around 90% of the students would like to use an AR app to learn other topics in Structural Analysis as well as other engineering subjects.

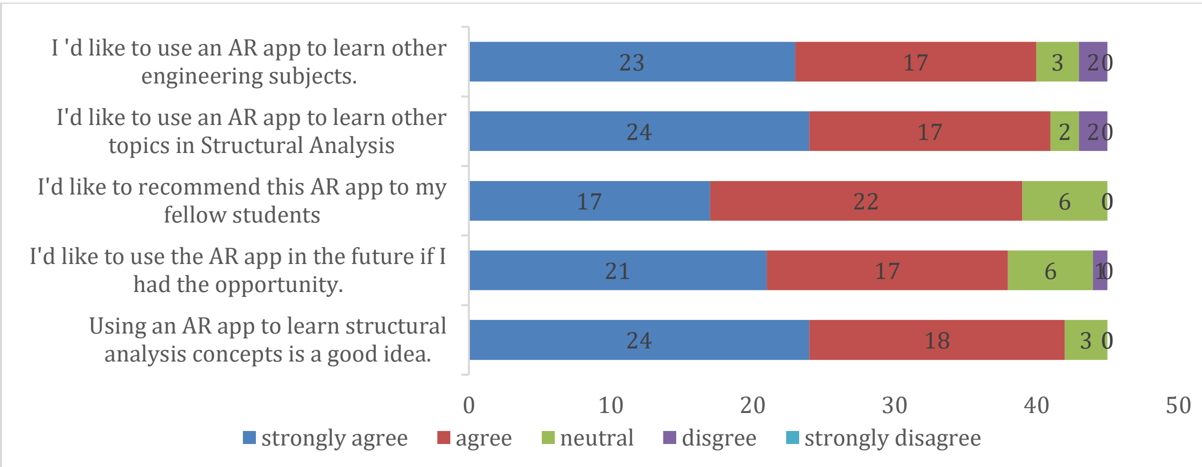

Figure 4. 5. Students' overall attitude and intention to use of the AR app

CHAPTER 5. DISCUSSION AND CONCLUSION

Introduction

This study aims to investigate the learning effectiveness of a pedagogical approach involving augmented reality technology in teaching structural analysis and examine student's perceptions of using augmented reality to learn structural analysis concepts. To achieve the research goals, a self-developed AR application was piloted in an undergraduate-level structural analysis course. The application was designed to help students to visualize the structural behaviors as well as linking structural representations with physical structures. Through the application, a real campus building is superimposed with a virtual representation of the structure to demonstrate simply-supported beams. The application allows students to adjust the load forces while observing the reaction forces, the deflection shape and magnitude on the structural system through the graphical representation of the building.

Discussions

The study first examined if students improved their overall test score from pretest to posttest inside each group by conducting paired samples t-test. The results found that there was no significant difference in pretest and posttest for both groups, which indicates that the students in both groups didn't significantly improve their overall test scores after the lesson. The reason for this is not clear. However, it is hypothesized that the posttest was harder to students than the pretest. This would also correlate with the high standards of deviation seen throughout the result data. An independent samples t-test was later performed to conduct between-group comparisons, which helped to answer the first research question regarding learning effectiveness of AR approach. The results of the between-group comparison show that no significant difference was found in the mean score change for the students who learned structural analysis concepts with traditional lecture and that of students who learned with iStructAR activity. The results indicate that the proposed pedagogical approach involving AR technology is equivalently effective to the traditional lecture-based approach in improving students' learning outcomes. In other words, this study confirms that using a pedagogical approach with AR technology, at a minimum, is as feasible and effective as traditional lecture-based approach for teaching and learning structural analysis concepts.

Although the quantitative results from knowledge tests are not significant, the students' positive attitudes toward the use of AR in learning structural analysis indicate the great potential of integrating this technology to teach engineering concepts. Most students reported that iStructAR is useful and enjoyable in leaning structural analysis concepts. This finding corroborates many previous studies in which students show good acceptance of AR and hold positive attitudes toward the use of AR in engineering education (e.g. Calderón & Arbesú, 2015; Fonseca et al., 2014; Frank & Kapila, 2017; Martin-Gutierrez et al., 2010; Martin-Gutierrez, et al., 2012; Riera et al., 2015).

Using AR to Teach Different Structural Analysis Concepts

Considering the test consists of three questions and each of those measuring different concepts. The test score of each question was then analyzed separately to further assess the effectiveness of AR approach in learning different concepts. The discussions below are organized by the individual questions. The students' feedback on the usefulness of AR in learning specific concepts is also discussed along with the test results.

Load type. In the first test question that measures student' understanding of load types, students were asked to label the live load and dead load on the given diagram. There was little difference regarding load type between the pretest and posttest. While the pretest diagram had one beam, and the posttest diagram had three. The number of beams didn't (shouldn't) influence the difficulty of identifying loads. No significant pretest-posttest change was found for this question in both groups. However, one explanation for this is the very high performance in the pretest, leaving little room for significant improvements. Most students already got full credits for this question in the pretest and maintained good performance in the posttest. The student's good performance might be related to the fact that load type is a simple and foundational concept in structural analysis and it is not hard to understand for most students. Thus, even though no significant difference was found in pretest-posttest comparison, it cannot be concluded that either AR or lecture-based approach is not effective in teaching load type. The between-group comparison also doesn't report statistically significant difference between the two approaches. This might be also due to the minimal pretest-posttest score change in both groups.

Turning to the survey responses, 87% of the respondents strong agreed or agreed that the use of this AR application was helpful for them to differentiate the different types of load. However, there were still four students who held neutral attitudes and two other students strongly disagreed with this. A possible reason for the negative feedback may be that both dead load and live load are represented in the same way: red color straight lines and arrows. Future design may differentiate the way how the two types of load are represented, which might help students to easily visualize the difference on the application surface.

Deflection Shape. In the second question, the students were asked to draw approximate deflection of beam/s. Both groups (AR and lecture-based) significantly increased the test scores for this question after completing the unit lesson, which indicates that both pedagogical approach are effective in helping students to understand how beam deflect under certain load conditions. However, the mean score change is not significantly different between the two groups. This indicates that AR and lecture-based approaches are equivalently effective in helping students understand the beam deflection behaviors.

Beam deflection behaviors under different loading conditions, such as different magnitude or location of distributed loads, are very difficult or even impossible to observe on a real building in physical world due to their very small nature. The traditional approach to show the behaviors of deflection to students is instructor drawing 2-dimensions static diagrams on blackboard or paper-based handout that are highly magnified from what would happen in the real world. With the power of AR technology, the students were able to interactively adjust the magnitude and location of live load (modeling people standing on the Skywalk in this case) applied on a physical building structure and observed the in-time beam deflection shape in the virtual structural representations. (The representation of the deflection on iStructAR was also magnified by a factor of twelve, allowing students to easily see the deflection shape.) Although the test results didn't show that AR approach is superior to traditional approach, the survey responses did reveal the potential of AR in enhancing student's understanding of deflection behaviors. Around 95% of the students expressed that being able to manipulate the magnitude and location of the load helped them understand how the load influenced the structural behavior.

Reaction force. In the third question, the students were asked to rank the supports by the magnitude of reaction forces from largest to smallest (each support experiences a reaction force). It is surprising that both groups got lower scores in the posttest and the score decrease was significant in the experimental group. A possible explanation for this might be the different challenge level of the two tests. As aforementioned, the structure that the students were asked to analyze in the posttest is a little more completed than the pretest. Specifically, the structure in the pretest has one beam and two supports; while the structure in the posttest has three beams and four supports (See the structures in Appendix C). The increasing number of supports in the posttest might make the question more challenging for the students. While having two supports allowed students only a 50% chance to get the question in the pretest right, having four supports allowed the students a much smaller percentage to get the question in the posttest right. The pretest question mirrored the simply supported beam structure in the AR app very closely; however, students did not seem to transfer knowledge from the AR activity to the posttest.

The between-group comparisons suggested that no significant difference was found in the score change of the two groups. The no significance can be explained in part by the design of the AR application. In this AR application, students are able to manipulate the live load and observe the instant change in the value of the reaction forces. However, this application doesn't explicitly show how the magnitude value is calculated, which was on purpose designed in this way to avoid heavy cognitive load. This aligns with the survey results that more than half of the students held neutral or negative attitudes toward the helpfulness of this AR application in understanding how to calculate load and solving structural analysis on their own. Both tasks require calculation in structural analysis.

It would be valuable to explore how to design an AR activity to optimize students' learning on this concept. A mix of the AR application supplemented with traditional learning could prove to be powerful. For instance, after teaching the reaction force calculation formula, an instructor can ask students to conduct a calculation first and use the AR application to check answers. As Joy and Garcia (2000) suggested, learning effectiveness is a function of pedagogical practices instead of the medium chose. Therefore, when using AR in engineering education, educators should take consideration of the instructional strategies together with the AR tools.

Summary

This study confirms the possibility that a pedagogical approach with AR technology can be equivalently effective to traditional lecture-based approach in teaching structural analysis. Although the quantitative results did not indicate the AR approach is superior than traditional approach in terms of improving students' learning outcomes, the survey responses suggested that AR is helpful for students to understand structural behaviors and build connections between physical building and graphic representations. The students particularly valued the interactive feature and in-time feedback of AR in understanding the deflection shape of a structure under different load conditions, a concept which is confusing to most beginning structural students. These features allowed students to freely manipulate the load and observe the immediate deflection change which is impossible to "see" in physical environment. More qualitative data may help us to establish a better understanding of the impact of AR in student's learning such as interviewing students what specific feature or function of this AR application help their learning.

Through examining the effectiveness of AR in helping students to learn different structural analysis concepts, this study indicates that students may benefit from the AR approach in different ways when they learn different types of knowledge. In other words, the effectiveness of AR in enhancing learning may vary with the different engineering concepts. Future research should be done to investigate how specific features (e.g. visualization, interaction, instant feedback, etc.) of AR could benefit students in learning different engineering concepts.

Limitations

This pilot study was only conducted in one structural analysis course. With a small sample size in control and experimental group, caution must be applied, as the findings might not be transferable to other structural analysis courses. Also, since the structural analysis concepts taught through the AR approach were relatively simple, it just required one unit of lesson (two class periods) to teach. Therefore, the time interval between the pretest and posttest was only one week. The test results might be influenced by the memory effect. A delayed-posttest would be carried out when approaching the end of the semester and the test results will be took into analysis to assess if the retention of knowledge may differ between the two groups.

Another limitation lies in the fact that limited concepts were taught through AR in this study. Since the AR application piloted in this study was designed to teach a few structural analysis concepts, this study only examined the effectiveness of AR in learning those concepts. As discussed above, the effectiveness of AR in enhancing learning may vary with the different engineering concepts. In other words, AR may be an effective approach to teach certain concepts but not some other concepts. Thus, the results of this study need to be generalized with caution to whole structural analysis subject or even other engineering subject matters. The AR application piloted in this study is the first module of an AR system and more modules are under development to teach other structural analysis concepts such as frame, truss, wind load, seismic, etc. The future research on those modules would provide more insights in terms of what type of concepts could be learned more effectively with AR.

Conclusions and Future Directions

This study investigated an innovative pedagogical approach involving AR technology to help students overcome the learning challenges in structural analysis. In specific, a mobile AR application, iStructAR, was developed to help students to visualize the structural behaviors as well as linking structural representations with physical structures. The AR system highlights the virtual beam indicating all the loads on the beam and allows students to manipulate the load forces while observing the deflection shape and the magnitude of reaction forces on the structural system through the graphical representation of the building. The AR application was piloted in a structural analysis class with a quasi-experimental design to assess whether this pedagogical approach is more effective than traditional lecture-based approach in improving students' learning outcomes. The students' perceptions on the AR application and AR technology were also examined.

The results showed that no significant difference was found between the score change of the control group and the experimental group. This study confirms the possibility that a pedagogical approach with AR technology can be equivalently effective to traditional lecture-based approach in teaching structural analysis. Through examining the effectiveness of AR in learning different structural analysis concepts, this study indicates that students may benefit from the AR approach in different ways when they learn different types of knowledge. For instance, in this study, the students particularly valued the interactive feature and in-time feedback of AR in understanding the deflection shape of a structure under different load conditions. Future research should be done to investigate how specific features (e.g. visualization, interaction, instant feedback, etc.) of AR could benefit students in learning different engineering concepts.

Although the quantitative results did not indicate the AR approach is superior than traditional approach in terms of improving students' learning outcomes, the survey responses suggested that AR is helpful for students to understand structural behaviors and build connections between physical building and graphic representations. Also, most students believed that using AR in classrooms would provide more interesting and engaging learning experiences. It is casually observed that the students collaborated with group members to solve problems with the AR application. While no students' interactions were observed in the control group. Increasing engagement and motivation, and encouraging collaboration are benefits of AR reported in many previous studies in engineering education (Alvarez, et al., 2017; Calderón & Arbesú, 2015; Fiorentino et al., 2009; Martín-Gutiérrez et al., 2015; Shirazi & Behzadan, 2014). It would be valuable for future research to investigate these benefits of AR in learning structural analysis. Formal observations could be utilized to collect data on student's engagement and collaboration.

This study also provides a few practical strategies for other educators to address the challenges reported in previous studies on using AR in engineering education. For instance, one of the challenges revealed from previous studies is that students' unfamiliarity with AR technology or using mobile devices for educational purpose may cause frustration (Fonseca et al., 2015; Shirazi & Behzadan, 2015). In this study, although most students don't have experience with AR technology (36 out of 45) and in using iPad for educational purposes (34 out of 45), the students did not reflect technical difficulties and most felt using AR makes learning more interesting. This may thank to the instructor's demonstration before handing out iPad to the students. The instructor utilized Apple Airplay to project the iPad screen on to the white board and demonstrated how to interact with the interface features. Each group was then asked to take an iPad and work with the AR application. The instructor and a teaching assistant were also available to answer questions during the group activity to ensure the students had smooth experiences with the new technology. Another challenge is related to display devices. Students found it hard to hold a tablet meanwhile interacting with the tablet surface. The AR application in this study solved that issue by allowing students to "pausing the camera" and freeze the image captured by the camera.

In addition to the contributions of this study to literature and practical work, this study reveals a challenge of class management involving AR activity. The AR activity was initially designed for outdoor environment in which students could stand in front of the physical building and through iStructAR, observe how the beams of the Skywalk deflect under different load conditions. This would help students build connections between traditional graphic representations and the physical building. However, in this pilot study, considering the difficulty to manage around 40 students outside, the activity was carried out in a regular classroom setting where students stand in front of a picture of the building on the wall. This may weaken the AR's capability to build connections between real building and graphic representations. In this pilot study, students were encouraged to try out the application outdoor after class. A few students did it and shared the screenshots with other classmates via Apple Airplay during the second class period. In future research design, it would be a good idea to have students try out the AR application in classrooms and ask students to use it outdoor as a homework. Instructors may assign a few tasks which require students to use the application in front of the real building at their own convenient time.

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APPENDIX A. SUMMARY OF ARTICLES FOR SYSTEMATIC REVIEW

Article	Subject	Research Design	Data collection	Findings
Alvarez, et al. (2017)	Mechanical Engineering; Industrial Design and Product Development Engineering	Randomly assigned two groups: control (blackboard in traditional classroom) experimental (AR in a computer room)	**Quantitative**. Student profile; class attendance; delivery of practical exercises; final exam attendance; survey	The experimental group displayed **significantly higher practical class attendance score, higher rate of practical work delivered, lower percentage of dropouts, and higher motivation survey score** compared to the control group, which suggests that the students who used 3D models with an AR app were **more motivated** than students in the control group.
Ayer et al. (2016)	Architectural Engineering, Civil Engineering	Three groups (same design activity): AR game, blank sheets of paper; and a paper-based approximation of the computerized game.	**Mixed method**. Pretest (knowledge, motivation, technology profile) and posttest (knowledge, perceptions); focus groups; actual design documents generated from the activity.	The students who used an augmented reality–based educational game completed the design activity with **better performance** in terms of considering more design concepts and more possible building materials in their designs compared with the students who used paper-based versions. AR group expressed similar level of interest and enjoyment to group with traditional approach,
Bendicho et al. (2017)	Chemical Engineering, Electronic Engineering	All participants completed 4 tasks without AR elements and 1 task with AR elements in same group	**Quantitative**: tests after each task, registration time of first attempt, remaining time to deadline.	**Reduced academic procrastination** was observed after introducing the AR. However, the cause-effect relationship need future test.
Calderón & Arbesú (2015)	Automation Engineering	All participants participated in an activity with AR	**Mixed**: Survey, casual observation	The survey reported that the AR app had **good acceptance** and facilitating learning. It was observed that all students centered their attention to the practice, which indicate the AR app increased student engagement and **motivation**.
Carbonell Carrera & Bermejo Asensio, (2017)	Engineering in general (map-reading skills)	Three groups: spatial skills workshop with AR (completed exercise with 2D and used AR to check answers), workshop without AR (only2D exercise), and control (no workshop)	**Quantitative**: pretest and posttest (Topographic Map Assessment)	Both groups who took the workshop (AR and only 2D) **statistically significantly improved their spatial skill test scores** (gains in AR group is higher than 2D group). No significant improvement was found in the control group. The results indicate that the workshop had positive impact on students' relief interpretation skills.

Dominguez et al. (2012)	Industry and Civil Engineering	Three groups: completed same exercises but used three different technologies: AR, VR and PDF3D	**Quantitative**: survey (satisfaction)	Students using AR are more satisfied than students using VR and PDF. It is observed by the teacher that students who used AR show more participation and motivation than students who used physical models.
Fiorentino, Monno & Uva (2009)	Mechanical Engineering	All participants used a AR tool for FEM Simulation	**Quantitative**: survey (usability)	Most students reported the AR toolkit **enhanced their understanding the mechanics of materiel**. The author reported the advantages of AR as an educational tool including supporting active learning; removing barriers between real and virtual model; elimating the expensive lab equipment.
Fonseca et al. (2014)	Architectural and Building Engineering	All participants completed the same experiment with AR	**Quantitative**: pretest (technological profile, knowledge, expectations) and posttest (assessment of course materials and AR); usability survey	Students' responses show **good acceptance** of AR technology in architecture education. It is observed that using the AR methods **improved student participation and motivation**. The students had statistically **significant increase in practical exam grade** (design activity) and spatial skills compared to previous academic year. The results also indicate that AR is a good system to visualize simple models, but it is less able to manage projects with high levels of detail and volume.
Fonseca et al. (2015)	Multimedia Engineering	All participants used AR to complete same course activity	**Mixed method**: usability test; qualitative test using UX techniques (both for user experiences)	The use of AR increased the student's motivation. However, it requires students more time to complete the project, which may result from the student's limited experience with using smartphone for educational purpose.
Frank & Kapila (2017)	Mechanical and Aerospace Engineering	All students interacted with test-beds with AR platform	**Quantitative**: knowledge pretest and posttest; survey	The students who used MRLE platform significantly improved their **test scores** measuring knowledge of dynamic systems and control concepts compared to pretest**.** The students reported they had **favorable experience**s with the platform. The platform can be used as a **cost-effective** approach to **enhance hands-on laboratory.**
Martín-Gutiérrez, Contero, &	Mechanical Engineering, Agricultural Engineering	Two groups: Experiment (took spatial training with AR) and control (no spatial training)	**Quantitative**: pretest and posttest (spatial skills measurement; satisfaction survey	same with above "experimental group significantly improved its spatial skills after performing this training compared to the control group that had not undergone any spatial skills training". p38

Alcañiz (2015)				
Martín-Gutiérrez et al. (2015)	Electrical Engineering	Randomly assigned two groups: experimental (used all three AR apps in four-month experiences) and control (traditional method, only received a demonstration after class over)	**Quantitative**: surveys	The Students reported that the three AR tools are easy to use and helpful for their learning. In this study, students were able to **learn both practical and theoretical content autonomously as well as collaborating** with other students without a teacher's assistance.
Martin-Gutierrez, Guinters, & Perez-Lopez (2012)	Electrical Engineering	All participants used AR app with either tablet PC or head mounted display HMD	**Quantitative**: number of students completing tasks; survey	Most students **were able to autonomously perform the operations properly** without any a teacher's assistance, which **save teacher's time** and improve training guidance. The students considered the AR tools **useful, interesting, and satisfying**. **cost-effective** technology
Martín-Gutiérrez et al. (2013a)	Industry and Civil Engineering	Four groups: AR, VR, PDF3D, control (no training)	**Quantitative**: Pretest and posttest (spatial skills measurement); course performance (not clear); success rate	Students who undertook the spatial ability training with AR showed better performance in **spatial skill** tests (higher mean performance and success rate) compared to control group, and slightly better than students who used the other two technologies.
Martín-Gutiérrez et al. (2010)	Mechanical Engineering	Two groups: Experiment group (took spatial training with AR) and control (did not undertake spatial training)	**Quantitative**: pretest and posttest (spatial skill measurement); survey	The results indicate **statistically significant improvement of spatial skills** in the group of students who took the training with AR. In Contrast, no significant improvement in control group. Overall, students expressed **positive attitude** toward the training materials and contents. The study also shows that AR is a **low-cost solution** to expensive lab equipment.
Martin Gutierrez & Meneses Fernandez (2014)	Mechanical Engineering	Two groups**:** Control (traditional class notes) and experimental (Augmented Book)	**Quantitative**: exam; surveys	The students who used augmented book to learn mechanical elements have statistically significant **better academic performance** and were **more motivated** than students who used traditional class notes to learn. Students considered the augmented book as an intuitive tool and **felt comfortable** to work with.
Martín-Gutierrez,Trujillo, & Acosta-	Engineering in general (a number of	Two groups: Experiment (took spatial training with AR) and control (no spatial training)	**Quantitative**: pretest and posttest (spatial skill measurement)	Statistically significant **increase in spatial skills** was found in the experimental group who took the spatial training compared to the control group.

Gonzalez (2013b)	engineering programs)			
Monroy Reyes et al. (2016)	Mechatronics engineering	All participants experienced AR	**Quantitative**: Survey	The study results indicate a good level of acceptance of using AR tool in university laboratory among students, laboratory technicians, and teachers. However, limitations include cost of AR equipment, difficulty in terms of requiring teachers time to design and implement it in lessons, AR glasses uncomfortable to use.
Ramírez Juidías et al. (2017)	Industrial Engineering	All completed visualization activity using three types of visualization object: 2D (traditional learning), 3D (computer learning) and AR (interact with 2D and 3D). all objects were presented as pared comparisons	**Quantitative**: survey (pre- and post)	The students recognized the important role of both traditional 2D display and computer 3D depictions where traditional 2D display provides the theoretical base in spatial understanding of objects and 3D improve the overview of the object. In terms of AR, the students **did not recognize usefulness of AR in developing the spatial skills.**
Redondo et al. (2013)	Architecture and Building Engineering	Two groups: control (traditional lectures) and experimental (AR). Involves four cases	**Quantitative**: pretest and posttest (academic performance), usability survey	Students' **positive responses** to the usability test confirmed that AR tech can be used in educational environments. results also indicate the AR can help to **improve students' graphic competences and spatial skills**, then improve academic performance. "AR **facilitates social dissemination**" p 60
Riera, Redono, & Fonseca (2015)	Architecture and Building Engineering	All participants use the same AR app (for three building projects)	**Quantitative**: usability test, surveys	This study examined the usability (effectiveness, efficiency, and satisfaction) of using AR in educational environments. Students held **overall positive attitudes** toward the usefulness of this technology for both their learning and future professional work, which confirm the feasibility of using AR in education context.
Shanbari et al. (2016)	Construction Engineering ("construction management program")	Randomly assigned three groups with different treatments: standard lectures without AR video; standard lecture and AR video; no lecture, only ART video.	**Quantitative**: pretest and posttest (assembly test involving multiple elements), course assignment	The results indicate that the augmentation **video increase students' understanding** and identification of brick veneer wall and roof elements (detected significantly more times by students who watched the augmentation video than who only were only exposed to the lectures.**)** The augmentation video achieves best results when used as a supplement to the class lectures.

Shirazi & Behzadan (2014)	Construction and Civil Engineering	Randomly assigned two groups: control (conventional instruction: computer slides, lecture notes, and textbook) and experimental (teams, CAM-ART on own tablets or smartphone).	**Quantitative**: Background presurvey, pretest, posttest, and long-term test (CATs: classroom assessment techniques; feedback survey	Students who used the AR book have greater **improvement in assessment tests** compared to students who used traditional instruction methods in both short-term and long-term. The students found the tool more **interesting, motivating, and interactive** compared to traditional lecture-based methods. Results also indicate that the AR group "gained more **self-confidence and better technical knowledge**" after using the app (p. 8)
Shirazi & Behzadan (2015)	Construction and Civil Engineering	Two groups: control (traditional print manual) and experimental (AR)	**Mixed method**: performance, workload data, videotaped observation, student rating effectiveness of AR (survey)	Students who used the AR for content delivery **performed better** in respect to three primary measures (building volume, number of elements, completion time). Overall, the use of AR increased student i**nterest**, involvement in the experiment, **frequency of communication and exchanging ideas**. Students held **positive attitudes** toward using AR to learn abstract topics. This study supports the potential of **autonomous learning using virtual instructor**. The **challenge** of AR was also revealed from this study that student need more time to familiarize with new technology and more likely to be frustrated during the experiment.
Turkan et al. (2017)	Civil and Construction Engineering	Two groups: control (traditional board and chalk approach) and experimental (AR)	**Mixed-methods**: pretest and posttest; Survey (including qualitative data)	The AR application yielded similar test score gain compared to traditional textbook learning, which indicates that AR application could be as feasible as traditional classroom education in learning and practicing structural analysis problems. The students appreciated the 3D **visualization and interactive features** of AR.

APPENDIX B. AR ACTIVITY PLAN

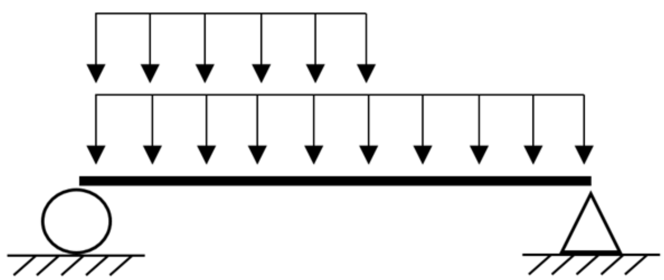
	Activity	Instructor	Students
Before experiment	Pretest	Monitor	Take the pretest during class
1st Class Period	Warm-up (5 min)	Talk about the structure of the skywalk.	Listen to the instructor and answer questions as needed
	Introduction to AR activity (5 min)	Introduce the activity to students and explain them what they are required to do.	Listen to the instructor
	Pre-AR activity (5 min)	Group students and Hand in the iPads & problem handouts	Find group members and grab iPads.
	In-group activity (20-30 min)	Observe students and answer any questions	Stand in front of structure pictures and solve problems on the handout with iPads
	Wrap-up (10 min)	Talk about common questions, plan for next class period	Listen to the instructor and submit hangouts
2nd class period	Warm-up (5 min)	Ask students briefly talk about how the activity went	Share opinions and perspectives
	Reflection (5-10 min)	Ask students some content related questions based on their observations and reflections and maybe make a list on the board	Explain their conclusions based on what they observed
	Lecture (20-30min)	Explain the equations and explanations based on student observations.	Listen to instructor; share screenshot they took during the last class
	Wrap-up (5 min)	Wrap up with any questions/concerns; Take back iPads	
	Posttest	Monitor	Take the posttest

APPENDIX C. KNOWLEDGE TEST

Pre-Test

The beam below is part of the third floor of a five-story building. The structure is an office building, with hundreds of employees working on each floor during the day. At one point in time, many people are standing on top of the beam, concentrated on the left half, creating a live load on the beam. The beam also experiences a load from its self-weight, known as a dead load.

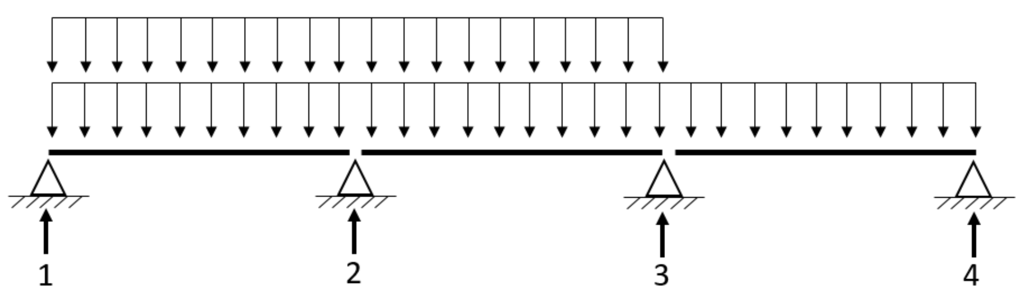
(1) Label the two different loads (live load, dead load) on the diagram below.
(2) Draw the approximate deflection of the beam.
(3) Circle the support that will experience the larger reaction force.



Post Test

A pedestrian bridge is composed of three simply supported spans, as shown in the figure below. Each span has the same length. At one point in time, many people are standing on top of the bridges, concentrated on the left two spans, creating a live load on the bridge. The bridge also experiences a load from its self-weight, known as a dead load. Assume that the live and dead distributed loads have the same magnitude.

(1) Label the two different loads (live load, dead load) on the diagram below.
(2) Draw the approximate deflection of each span of the beam.
(3) Each support experiences a reaction force, which is labeled in the diagram below. Rank the reaction forces experienced by the supports in order of magnitude from largest to smallest.



Order of Reaction Forces:
Largest ____ ____ ____ ____ Smallest

APPENDIX D. SURVEY

Dear Student,

We need your help to provide us with valuable information on your learning experience with the AR application. Your feedback will help us make improvements to the design of the application.

The survey has 17 opinion questions and 7 background questions. It should take you no more than 10-15 minutes to complete. Your responses are completely anonymously; so please give us your honest opinions and answers.

Be assured that your responses will be kept confidential and you will never be individually identified. Completion of the survey indicates your consent to participate. You may omit any question you are not comfortable answering, and you may quit the survey at any time.

Thank you for taking the time and effort to complete this survey. We really appreciate your input! If you have any questions, concerns, or complaints regarding this research, please contact Dr. Aliye Karabulut Ilgu ().

1. Please rate how helpful the AR activity was for you to:

	Very helpful	Somewhat Helpful	Neutral	Somewhat unhelpful	Very unhelpful
Visualize the structural components of a building	○	○	○	○	○
Differentiate different types of loads	○	○	○	○	○
Understand how to calculate loads	○	○	○	○	○
Analyze a structure	○	○	○	○	○
Visualize how a structural element deflects under certain loads	○	○	○	○	○
Visualize the reactions of a structure caused by certain loads	○	○	○	○	○
Draw a deflection shape	○	○	○	○	○

For question 2-17, please rate the statements on a scale of strongly agree to strongly disagree

2. Seeing the hidden structure of a building on campus through the AR app helped me visualize the connection between a model and the real building

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

3. Using the AR app allowed me to solve structural analysis problems on my own

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

4. Being able to manipulate the magnitude of the load in the app helped me understand how the load influenced the structural behavior (i.e. deflection shape, reaction forces)

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

5. Being able to manipulate the location of the load in the app helped me understand the effect that the load location has on structural behavior (i.e. deflection shape, reaction forces)

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

6. It was fun to use the AR app to see the hidden structures of a building on campus

- ☐ Strongly Agree
- ☐ Agree

- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

7. I think the AR system allows learning by playing

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

8. The use of AR makes learning more interesting

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

9. I enjoyed using the AR app

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

10. Learning through the AR app was boring

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

11. I believe the use of AR improves learning in a classroom environment.

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree

- Strongly Disagree

12. Using the AR app would facilitate better understanding of complex engineering concepts.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

13. I believe using an AR app to learn structural analysis concepts is a good idea.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

14. I would like to use the AR app in the future if I had the opportunity.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

15. I would like to recommend this AR app to my fellow students.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

16. I would like to use an AR app to learn other related topics in Structural Analysis.

- Strongly Agree
- Agree
- Neutral
- Disagree

- ☐ Strongly Disagree

17. I would like to use an AR app to learn other engineering subjects.

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

Please answer question 18-24 to let us know more about your background.

18. What's your Gender?

- ☐ Male
- ☐ Female
- ☐ Other

19. What's your major?

____

20. What's your year of study?

- ☐ Freshman
- ☐ Sophomore
- ☐ Junior
- ☐ Senior
- ☐ Master

21. Do you currently own an ipad or another tablet?

- ☐ Yes
- ☐ No (skip to question 24)

22. How often do you use the iPad/tablet?

- ☐ Daily
- ☐ Weekly
- ☐ Often
- ☐ Sometimes

- ☐ Never

23. What do you usually use your ipad/tablet for?

- ☐ Chat and Email
- ☐ Browse websites
- ☐ Study
- ☐ Game
- ☐ Music and Movies
- ☐ Other___________________

24. Do you have any experience with Augmented Reality?

- ☐ Yes, please describe briefly__________________________________
- ☐ No

End of the survey. Thank you!

APPENDIX E. IRB APPROVAL DOCUME

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 6/14/2017

To: Dr. An Chen
426 Town Engineering Bldg

From: Office for Responsible Research

Title: Collaborative Research: Transforming Teaching of Structural Analysis through Mobile Augmented Reality (NSF Proposal #: 1712049)

IRB ID: 17-307

Study Review Date: 6/14/2017

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

- (1) Research conducted in established or commonly accepted education settings involving normal education practices, such as:
  - Research on regular and special education instructional strategies; or
  - Research on the effectiveness of, or the comparison among, instructional techniques, curricula, or classroom management methods.

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

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**

- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

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

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

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