Innovations in Education and Teaching International

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/riie20

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INNOVATIONS IN EDUCATION AND TEACHING INTERNATIONAL
https://doi.org/10.1080/14703297.2022.2058050

The effectiveness of an augmented reality app in online civil engineering learning

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ABSTRACT

In this study, an AR-based mobile learning application is proposed to assist online civil engineering course learning during the COVID-19 pandemic. A quasi-experiment has been conducted, and feedback from both the teacher and students has been analysed to examine the effectiveness of the proposed approach in terms of learning achievements. The subjects were 46 sophomores who majored in civil engineering in one class taught by one instructor in a southern U.S. state university. The quasi-experimental results showed that the proposed approach could not significantly improve the students' online learning achievements. However, the feedbacks brought some explanation to this non-significant result. They indicated that students found this mobile AR app to be an interesting, helpful, practical, and effective approach in their online learning that helped them gain more in-depth knowledge than traditional teacher-centred classroom instruction.

KEYWORDS

Augmented reality; civil engineering; quasi-experiment; online learning; mobile application

Introduction

In today's world of rapidly changing technology, the demand for education quality is getting higher (Niederhauser et al., 2018). Traditional classroom lectures alone hardly appeal to students (Bond et al., 2020; Trespalacios & Lowenthal, 2019). Therefore, educators constantly seek new methods and tools to enhance students' interests and improve learning. Among educational technology (EdTech) tools, augmented reality (AR) has attracted much attention due to its various characteristics (Sırakaya & Alsancak Sırakaya, 2020). AR allows users to see the real world with virtual objects superimposed upon or composited with the real world (Azuma, 1997). With technological development, the application of AR should increase shortly (Akçayır & Akçayır, 2017). The Horizon Report, published by The New Media Consortium (NMC) in recent years, lists AR as one of the six technologies with the most significant potential for the next few years. AR has many potential benefits in the learning process. For example, students may take a more substantial role, and self-regulation, motivation, and interest may increase in a task, and the teaching materials and content may be explored (Cheng, 2017). AR also facilitates the

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development of constructivist and ubiquitous learning (López Belmonte et al., 2019). The students learn better with AR than printed media or software (Radu, 2014). AR may reduce teachers' workload, too (Akçayır et al., 2016). Furthermore, AR is found to have the most positive impact on academic achievement (Altinpulluk, 2018). AR certainly has its limitations, such as the need for previous training. It might not be accessible and may reduce sociability (Gómez-Galán et al., 2020). However, compared to researches of other more mature technologies in education (multimedia, web-based platforms), AR applications in education are still in an early stage. There is little evidence of AR's effects on teaching and learning (Wu et al., 2013), and scientific productions on AR in higher education are not abundant (López Belmonte et al., 2019).

Most of the AR studies in education were based on face-to-face instructions. According to a review of 28 articles from 2010 through 2017 (Ibáñez & Delgado-Kloos, 2018), 19 articles' education context was in the classroom, and only one learning activity took place at home. In another review, only two of 58 AR studies took place at home (Altinpulluk, 2018). However, the COVID-19 Global Pandemic from the beginning of 2020 has significantly impacted the education system, forcing schools to be closed, affecting an unprecedented number of students worldwide (Vuță, 2020). The worrying of virus evolution, coupled with the closure of schools, has put tremendous pressure on the education system, forcing educators to make urgent adjustments to ensure the continuity of learning. Therefore, online technology is used to help continue teaching and learning (Puspitasari & Suryadarma, 2021). This has led to the rise of e-learning, namely teaching through remote and digital platforms (Vuță, 2020). Traditional face-to-face teaching has been turned into online teaching overnight. AR technology can be applied to education to provide a solution (Hidayatulloh et al., 2021; Yang et al., 2020) and might be an innovative measure to deal with the impact of COVID-19 on the education system (Vuță, 2020).

As mobile devices now support AR applications (App), educators who wish to use AR technology do not need to conduct scientific experiments in computer labs (Akçayır et al., 2016). Mobile devices can offer an ideal platform for AR applications because they are pretty cost-effective and easy to use (Akçayır & Akçayır, 2017). In addition, most AR App in education is related to natural sciences, mathematics, and statistics. However, only four out of the 61 studies on AR App in education involve engineering, manufacturing, and construction. Scarcity of the data results in the impossibility of deciding the effect size on them (Garzón et al., 2019). Another review showed that only 5% of AR-STEM studies are performed in engineering (Sırakaya & Alsancak Sırakaya, 2020). Therefore, this article aims to discover the effect of mobile AR on online engineering course learning.

Hypotheses (research questions)

Based on the theories above and in response to the above issues, the authors designed quasi-experimental research on AR-based STEM learning in higher education and developed a mobile phone AR App to help students' online learning during the COVID-19 pandemic. To add to the existing literature, the authors hoped to measure student learning outcomes and students' attitudes towards AR-based online civil engineering learning through the following two research questions

(1) Does the AR App effectively impact students' learning outcomes in online civil engineering learning?

(2) What are students' and instructors' perspectives on using AR App for learning civil engineering online?

Methodology

Participants

A class of 46 sophomore students (age 19–21, M = 19.7, SD = 0.64) who majored in civil engineering in one historically black college and university (HBCU) at a state located in the south of United States participated in this study for one semester. Unfortunately, eight students did not complete both tests and thus were not considered for this study. Among the 38 respondents, 23 (60.5%) were male, and 15 (39.5%) were female. They had learned civil engineering for one year but never had used a mobile AR App in this course before.

Research Design

This study employed quantitative and qualitative data collection tools in the online undergraduate civil engineering course. Quantitative data was collected through two achievement tests to define the effectiveness of the AR app in helping students' online learning. Qualitative data was collected through the students' course evaluations at the end of the semester and the instructor's comments on AR-assisted online learning. The experiment lasted for 14 weeks in the fall semester of the 2020 academic year. The teacher taught Structural Mechanics, focusing on force analysis and internal force chart drawing of statically determinate structures. By the end of the semester, the students should be able to analyse the geometric composition of the structural system and determine the number of statically indeterminate structures. Though students' total scores consisted of formative assessment like participation and assignment and summative evaluation like midterm and final tests, this research only focused on the two tests for their accuracy in reflecting students' learning. Due to the COVID-19 pandemic, all teaching, learning, and testing were done online through the CANVAS system on the school website and ZOOM meeting software at home. The AR App designed by the authors is a vector computing mobile AR app (Figure 1). Vector calculation is fundamental in engineering mechanics, which is involved in almost every chapter. But it's very abstract. Therefore, it is difficult for the students to understand vector calculation in online learning without the teacher's on-site guidance. This AR App can help students visualise vectors arithmetic and intuitively understand this abstract topic. This research integrated the teacher, the textbook, ZOOM software, and the mobile AR app to construct a learning environment supporting all design parameters listed previously.

Data collection tools and process

A two-stage implementation procedure was adopted to draw valid conclusions and explanations about student learning: (1) Stage 1 included two achievement tests before and after applying the AR app, and (2) Stage 2 included qualitative analysis of students' comments on this course.

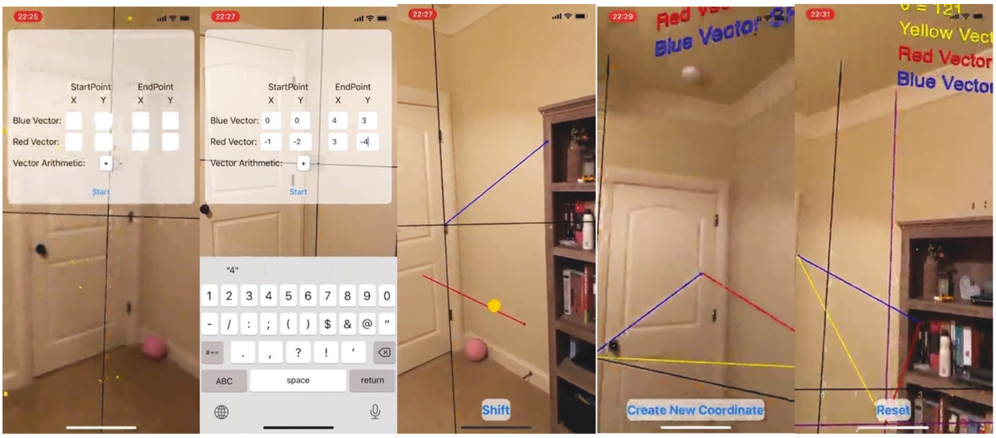

Figure 1. Operation interface of the mobile AR app.

During Stage 1, a quasi-experiment was conducted to collect quantitative data, including midterm and final tests, and the Wilcoxon Signed Ranks Test was conducted to compare the results. The midterm exam was used as the pre-test, and the final exam was used as the post-test. Both tests consisted of 12 multiple choices and four calculation questions, assessing recalling knowledge and complex problem solutions. The AR App was not allowed during the tests as mobile phones were prohibited in tests according to the school rules. Before the midterm exam, the students calculated vectors and matrices manually; the AR App was used to assist the calculation after the midterm exam. The pre- and post-test were designed on the same course content. The opinions of other teachers with more than five years' experience in civil engineering courses were received to ensure the reliability and validity of the two achievement tests.

In Stage 2, the university's end-of-term evaluation system collected qualitative data about the students' attitudes and suggestions for using AR App. At the end of the semester, students needed to fill in their evaluations on the school website, including students' comments towards the instructors and the courses. These comments were good sources for this research as qualitative data. In addition, the researcher conducted a short interview with the instructor, in which the instructor's opinions about the AR app were sought.

Data analysis

Quantitative analysis

SPSS 25 statistical analysis software was used to analyse quantitative data. First, descriptive statistical analysis was used to determine the mean, standard deviation, and normality test of the midterm and final tests, to determine whether to use parametric or non-parametric tests to compare the performance differences between the mid-term test and the final one. Then corresponding statistical test was taken to determine whether the difference between the two tests was statistically significant. Finally, the researchers could determine whether the use of AR App could significantly improve students' online civil engineering course learning performance and answer research question one.

Qualitative analysis

In text analysis, content analysis is often used for coding (Akçayır & Akçayır, 2017; Wang et al., 2018). Therefore, the content analysis method and NVivo 12 software was applied to analyse students' evaluation and the instructor's comments to understand their perspectives on the mobile AR App. Firstly, both the students and the teacher's comments were coded, and themes were found. Next, the codes were rearranged according to those themes. Finally, word frequency analysis was used to make the reporting of the findings more comprehensible and objective. The content analysis results were used to answer research question two and explain question one.

Results/findings

Quantitative findings

After a semester of experiments, 46 students' mid-term and final grades were obtained. However, because some students did not take both tests, only 38 valid data remained. According to the descriptive statistics, the mean of the midterm was 25.26 (SD = 5.386), and the mean of the final was 22.5 (SD = 6.845). To determine whether to use a parametric or non-parametric test to detect the statistical difference significance, the authors carried out several normality tests for the score distribution.

Since the quantity of students 38 was small, the Shapiro-Wilk test should be used instead of the Kolmogorov-Smirnov test. The results of the Shapiro-Wilk test (Table 1) showed that the significance of normality tests was 0.141 ($P > 0.05$). Therefore, the difference value of the two exams' scores was normally distributed.

The histogram and Q-Q plot were used to visually observe the distribution of the difference value of the two exams' scores. The histogram (Figure 2) showed that the difference value was skewed and did not conform to the normal distribution. The Q-Q plot (Figure 3) showed that the difference value deviated from the middle straight line, indicating that the difference value of the two exams' scores was not normally distributed.

The result of the Shapiro-Wilk normality test was contrary to the display of the histogram and Q-Q plot. As the sample size was small, the reliability of the Shapiro-Wilk normality test was less than the histogram and Q-Q plot. Therefore, it could be decided that the difference value of the two exams' scores did not conform to the normal distribution. As the sample size was 38, which is not large enough to ignore the normality distribution, it was not suitable to use the parametric statistical test (Paired Sample T-test) to judge the significance of the difference between the two results. Instead, the non-parametric statistical test should be used to judge it. Because the same students took the two tests, the Wilcoxon Signed Ranks Test should analyse the significance of the difference between the two test scores.

Table 1. Shapiro-Wilk normality test of difference value of two exams' scores.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Difference	.161	38	.014	.956	38	.141

a. Lilliefors Significance Correction

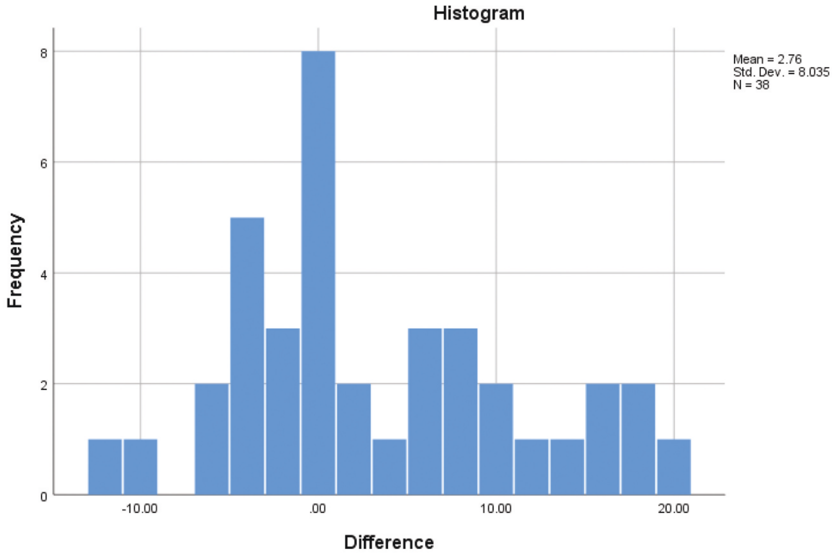

Figure 2. Histogram of difference value of two exams' scores.

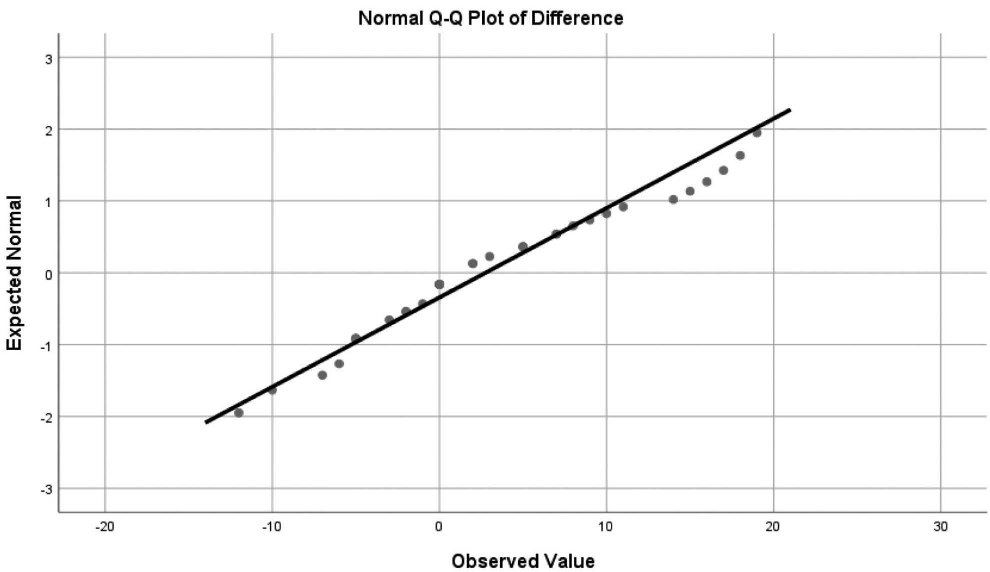

Figure 3. Q-Q plot of difference value of two exams' scores.

Table 2 and Table 3 showed that the P-value of the Wilcoxon Signed Ranks Test was 0.063 ($p > 0.05$). Therefore, there was no significant difference between the mid-term exam and the final one at the 95% confidence level. Therefore, the answer to research question one was that after a one-semester experiment and application, the AR app did not effectively impact the learning outcomes in online civil engineering learning.

Table 2. Score ranks of midterm and final exams.

Ranks				
		N	Mean Rank	Sum of Ranks
Final – Midterm	Negative Ranks	18[a]	19.03	342.50
	Positive Ranks	13[b]	11.81	153.50
	Ties	7[c]		
	Total	38		

a. Final < Midterm
b. Final > Midterm
c. Final = Midterm

Table 3. Wilcoxon signed ranks test.

Test Statistics[a]	
	Final – Midterm
Z	−1.856[b]
Asymp. Sig. (2-tailed)	.063

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

Qualitative findings

At the end of the semester, the students completed the course evaluation, and the instructor provided his comments on the AR-based online course. Based on their comments, the authors used the content analysis method to analyse their views on using the AR app to learn the online civil engineering course. The feedbacks of both the students and the teacher were coded, and themes were found. There were two themes with three core categories and ten codes shown in Table 4.

Table 4. Content analysis of comments from students and teacher.

Theme	Core Category	Code
Positive perspective	motivation promotion	create a more interesting, realistic, joyful, interactive learning environment
		motivating the students' interest/willingness to fulfill the tasks
	ease of use	make complex tasks more comprehensible
		more comfortable and easier to finish assignments
		less/shorter time to complete assignments
		better understanding the calculation process
		help retention of course concepts
	high effectiveness	less need for help (from the teacher) /reduce teacher's workload
		help autonomous learning
		highly effective and recommended tool
Negative perspective	cognitive overload	lack the teacher's face to face practical instruction
		The App is not as intelligent as a teacher to help students according to their aptitude
		The App focuses on observation and uses, rather than inducing students to think
	technical challenge	more challenges related to technical difficulties in learning
		damaging student's eyes
		App did not work well on old mobile phone and android system
	overuse of App	rely too much on App to calculate and lose the basic hands-on ability
		more time on App and less time studying
		focus on the AR app rather than the teacher's instruction and textbook concepts
		excessive use/overuse of App leads to a decrease in-class participation

To clarify the main benefits and drawbacks of the AR app, the researchers further used NVivo's word frequency analysis to obtain keywords that students and the teacher repeatedly mentioned, to know their main perspectives. According to NVivo's word frequency analysis, the word 'easier' was mentioned 8 times, 8 'help', 8 'interesting', 7 'complex', 7 'difficult', 7 'effective', 7 'realistic', 6 'interactive', 6 'overuse', 6 'practical', 6 'problem', 6 'problems', 5 'better', 5 'challenges', 5 'joyful', 5 'useful'. This word frequency result showed the main pros and cons of the AR App and supported the above content analysis of the feedback. The positive and negative perspectives keywords can be found in this word frequency list. The students and the instructor's perspectives on using AR App for learning civil engineering online could be found in both the content analysis and the word frequency analysis to answer research question two.

Discussion and conclusion

After a semester of the experiment, through Wilcoxon Signed Ranks Test analysis, results of this study showed that the AR-assisted online learning had no significant effect on student achievement tests. Contrary to this finding, the results of most previous research pointed out that AR could significantly enhance student's learning achievements towards STEM courses (Akçayır et al., 2016; Chiang et al., 2014; Diao & Shih, 2019; Ibáñez & Delgado-Kloos, 2018; Puspitasari & Suryadarma, 2021). This might result from the following three negative impacts aggregated from the students' and the instructor's feedback.

The first negative impact might come from the situation that students encountered a great challenge when using AR App without the teacher's face-to-face instruction. Some students were good at learning new technology and could quickly learn and use AR App. Others might have difficulty in using the AR App by themselves. Complex tasks, combined with new technology, might result in cognitive overload. Second might be a technological challenge, together with pedagogical issues (e.g. unsuitability in an online course, teachers' inadequate experience with technology; Akçayır & Akçayır, 2017). Several students commented that the AR App did not function well in the Android mobile system (the App worked well in iOS), or their mobile phones were too old to run it well. When students do not have the necessary technical experience, they would likely experience problems using AR technology. Thus they might see no positive benefits in improving their skills (Akçayır et al., 2016). The third negative impact was the overuse of the AR App, resulting in students' incapability of hands-on ability to solve problems by themselves. For example, some students commented that they relied too much on AR App to do vector computing so that they could not calculate it without AR App. Therefore, students could do well with the AR App in their daily homework but failed to get satisfactory results in the exam when a mobile phone was not allowed. The above three negative impacts from the AR App might explain the insignificant difference between the two tests.

Despite the insignificant difference in the achievement test, the content analysis revealed benefits from applying this AR App. Most students and the teacher had positive views and welcomed this AR. They pointed out that the AR app created an interesting, realistic, joyful, and interactive learning environment to enhance students' learning motivation. In addition, it might help the students cope with complicated calculations and make complex tasks more understandable and easier to understand. This AR App even reduced the instructor's workload since the students could rely on the AR App for learning and needed less help from the teacher. Therefore, this AR App was still valid, but the three negative impacts need concerns. In recent large-scale experimental research on EdTech, Fairlie and Loyalka found that EdTech needs to be carefully used as a full-scale substitute for traditional instruction. EdTech can substitute for traditional learning only to a certain extent, and there are limits on how much it may be beneficial (Fairlie & Loyalka, 2020).

Limitation and suggestion

This study has several limitations, especially some methodological flaws. The internal validity of this research may be weak due to the absence of a control group. The generalisability of the findings seems limited as only one class of sophomores in an HBCU was involved. Furthermore, this research focused only on students' achievement and attitude; it might be interesting to research students' cognitive and emotional features. Qualitative analysis played an essential role in this research, but the data came from the course feedback, and no questionnaires or interviews for students were conducted. Sırakaya and Alsancak Sırakaya found that there had been few qualitative studies in the last six years and believed that more qualitative research in the future might fill the gaps in the existing literature in the scope of application of AR in STEM education (Sırakaya & Alsancak Sırakaya, 2020).

Some subjective reasons, such as methodical limitations in the teaching process and quality of instructional design, need attention. A sufficient understanding and adequate course content preparation should become requisite for future course design, and the students need to be trained to use AR App. AR App needs to be developed meticulously based on cognitive and emotional standards for students to reduce the difficulty of adapting to the new AR app. Schools might provide more online learning support to students in need, ensuring students have digital devices to continue their E-learning, especially in this post-pandemic and post-digital age.

Funding

This work was supported by The National Science Foundation (NSF) in the United States, Grant ID: HRD 1818672.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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