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A Comparative Study of Traditional and Augmented Reality-Based Engineering Drawing Instruction: Effects on Visualization Skills and Cognitive Load

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Abstract: Augmented reality (AR) is utilized in education to enhance students' skills and learning experience. We developed an AR-based application for engineering drawing (ED) courses, evaluating its impact on 3-D visualization skills and cognitive load. The study involved 392 first-year engineering students, with a control group using conventional methods and an experimental group using the AR application. Results showed that the experimental group outperformed the control group in 3-D visualization skills and experienced lower cognitive load. Students responded positively to the application, indicating that AR can enhance learning performance and experience in engineering education.
Keywords: Augmented reality, marker-based, cognitive load, system usability, engineering drawing

1. Introduction

Augmented reality (AR) technology enhances education by providing an interactive experience where computer-generated information augments the real world (Azuma, 1997). It helps students to visualize abstract concepts, increases motivation, and develops 3-D visualization skills. This study focuses on using AR in an Engineering Drawing (ED) course to improve spatial abilities and reduce cognitive load. A marker-based AR application was developed and evaluated using the System Usability Scale (SUS). Student feedback was collected to identify strengths and weaknesses of the application for future improvements. The specific research questions (RQ), this study intends to answer are as follows:

- RQ1: Can AR based learning improve students' visualization of 3-D objects in ED courses compared to the conventional instruction method?
- RQ2: Can AR-based learning in ED reduce students' cognitive load relative to conventional ED learning?
- RQ3: Is the augmented reality-based application easy to use for the ED course?
- RQ4: How satisfied are students with the AR-based learning method?

2. Related work

2.1 Augmented reality and its role in field of Engineering Drawing

AR integrates computerized information into the real world and has been implemented in various disciplines, including education, recreation, tourism, and healthcare. In education, AR has helped in developing immersive and interactive learning environments (Kaufmann & Schmalstieg, 2003). It enhances the classroom by providing real-time response, simulations, and visual aids, increasing student engagement and understanding. AR has improved learning outcomes and motivation across different educational contexts, making difficult ideas more accessible (Chang & Hwang, 2020). Interactive AR simulations has enabled students to manipulate virtual objects and observe their behavior, simplifying the comprehension of abstract concepts (Bacca et al., 2014). ED is an important course in engineering education, but students struggle with visualizing 3-D objects from 2-D drawings (Pando Cerra et al., 2020). There have been studies where AR has enhanced learning by providing interactive experiences, generating 3-D models, offering visual aids, and enabling practical experience (Danakorn Nincarean et al., 2019; Martín-Gutiérrez et al., 2019). AR has also assisted in boosting motivation, engagement, and enjoyment in ED courses (Wei et al., 2011).

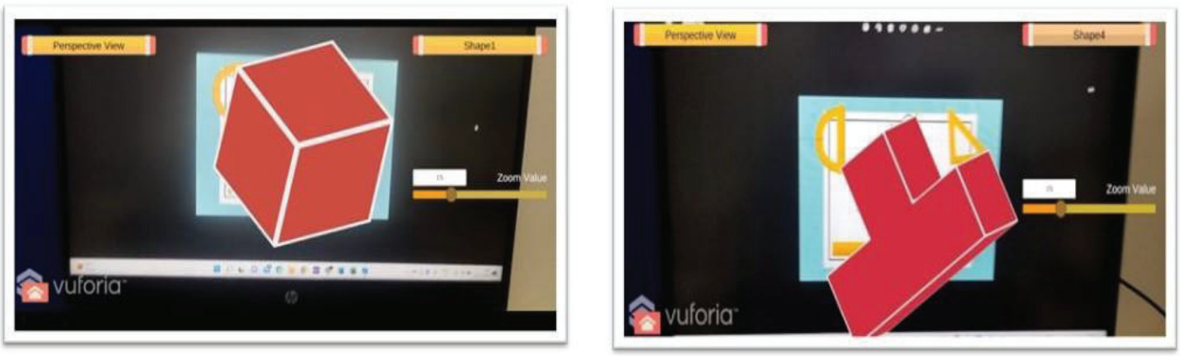
2.2 *Cognitive load theory*

Cognitive load theory (CLT) suggests that reducing the cognitive load enhances learning. Multimedia, like images and videos, can increase cognitive burden, but interactive media can facilitate learning (Sweller et al., 1998; Mayer & Moreno, 2003). AR decreases cognitive load by providing an immersive and interactive learning environment (Billinghurst & Duenser, 2012). Lee (2012) found that AR significantly reduced cognitive load in science learning compared to traditional methods. However, the effectiveness of AR in reducing cognitive load depends on system design and learners' prior knowledge (Huang et al., 2020).

3. Methodology

3.1 Research design and sample

A pilot survey was conducted to identify challenging topics in ED. Participants included 53 undergraduates and 18 experts. The survey revealed difficult areas such as solids projection, cross-section, points, planes, and auxiliary planes. A true-experimental design was employed with 392 randomly selected students (291 males, 101 females) aged 19-22. The experimental group used an AR app, while the control group followed traditional methods. Each group consisted of 196 students. In this study, we developed a marker-based AR application using Unity[1] software to enhance 3-D visualization skills in an ED course. The application included sections like orthographic view, projection of solids, and cross-section of solids. Users selected sections, pointed their device's camera at markers, and viewed 3-D models. They could interact with the models by rotating, moving, and resizing them. The application provided various shapes and angles for visualization. Users were recommended to explore all sections within a week to fully utilize its features (see Figure 1).



(i) (ii)

Figure 1. User Interface of application.

[1] https://unity.com/

3.2 Instruments

We administered a pre- and post-test containing 8 test items each to evaluate 3-D visualization skills, validated by subject expert (see Figure 2). Students were given 10 minutes to complete this test. Thereafter, we used a cognitive load questionnaire for analyzing students' extraneous cognitive load and intrinsic cognitive load during the experiment (Hwang et al., 2013). SUS, created by Brooke (1996), was used for evaluating the usability of the AR application. It consisted of ten items on a five-point Likert-scale. Students were given 25 minutes to complete the post-test questionnaires. The Cronbach's value for all questionnaires was greater than 0.7, which is acceptable (Barrett, 2001). We used a questionnaire to obtain qualitative feedback on our AR application. It consisted of 10 subjective questions through which students could discuss their experience using the application, thereby providing more support to our findings. The questions were like: “Do you have any previous experience of using AR app?”, “How much would you rate the app? “, “Did you find the AR useful?” etc.

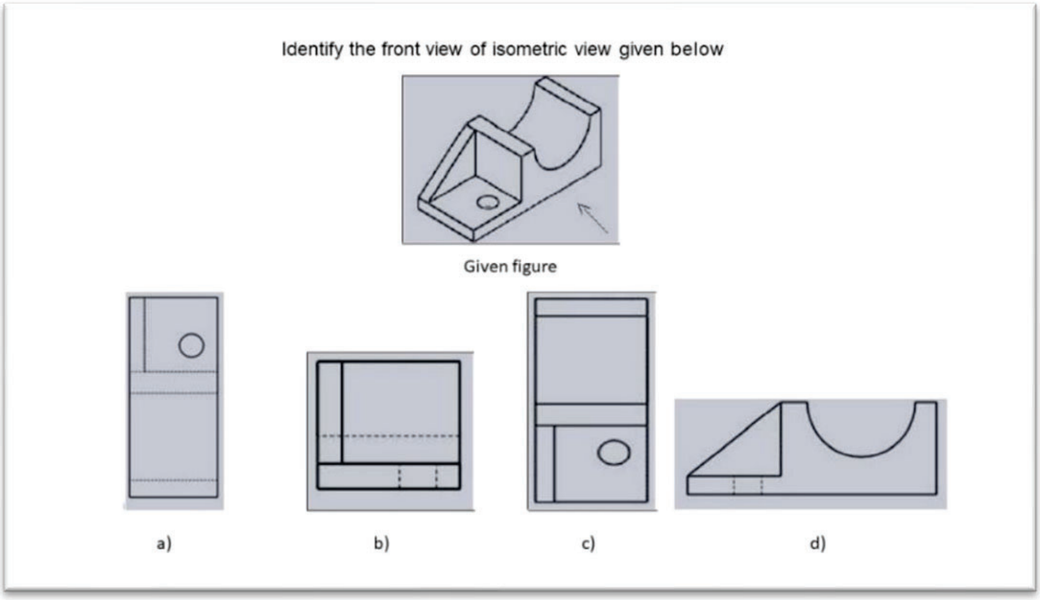


Figure 2. Example of questions included in pre-test and post-test.

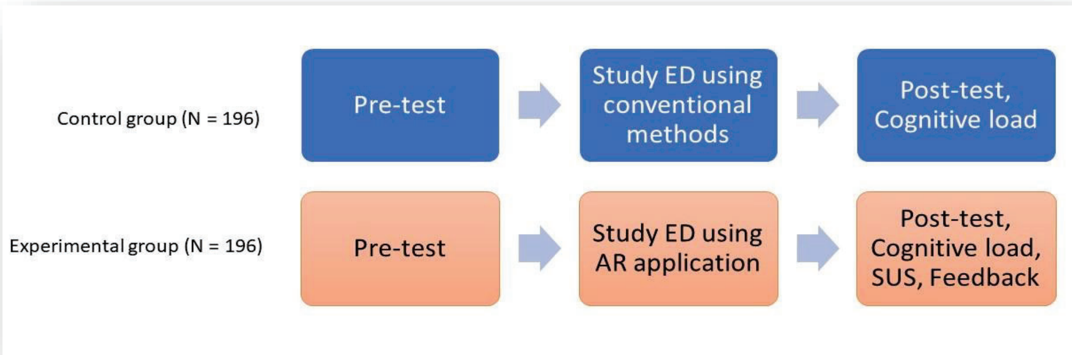


Figure 3: Experimental design

3.3 Procedure

Figure 3 depicts the experimental procedure of the investigation. The study consisted of three stages: (1) Both groups were obliged to complete the pre-test within the allotted time; (2) the experimental group was instructed to use the application to study ED for one week; and (3) both groups were required to complete the post-test. The experimental group was subsequently required to complete an SUS questionnaire and provide qualitative feedback.

4. Results

We examined the data using descriptive statistics. The learning outcomes of the experimental group and the control group were compared using t-test methodology. We used SPSS version-21 for result analysis.

An independent t-test was employed to analyze the results, and the effect size (Cohen's d for various sample sizes) was computed to demonstrate the extent of difference between the groups. In the pre-test, there was no significant difference between the control and experimental groups (t = 0.30, p > 0.05). In contrast, the post-test revealed a significant difference between the control and experimental groups (t = 11.14, p < 0.05). In addition, we conducted a t-test on the learning gains of both groups. There was a significant difference in performance between the control and experimental groups (t = 6.64, p < 0.05; see Table 1).

Table 1: Means and standard deviations of the pre- and post-test for each group.

Group		Mean	*SD*	*MD*	*t-value*	*p*	Effect Size
Pre	Control group	4.37	2.31	0.07	0.30	0.78	0.03
	Experimental group	4.44	2.29				
Post	Control group	4.34	2.68	2.01	11.14*	0.00	1.00
	Experimental group	6.41	1.11				
Gain	Control group	0.02	3.21	1.93	6.64*	0.02	0.67
	Experimental group	1.96	2.51				

Note. * p <.05. *SD* = Standard deviation, *MD* = mean difference

An independent t-test was conducted to examine the impact of the AR-based learning approach on the intrinsic and extraneous cognitive load of students. The results showed a significant difference between the two groups in terms of mental load (t = 16.78, p < 0.05) and mental effort (t = 15.86, p < 0.05; see Table 2). These outcomes implied that the AR-based application had a significant impact on the students' intrinsic and extrinsic cognitive loads.

We calculated SUS score using technique proposed by Bangor et al. (2008). The total SUS score was 92.1237. Figure 4 depicts the SUS analysis and feedback obtained by students.

Table 2: Means and standard deviations of cognitive levels of each group.

	Group	Mean	*SD*	*MD*	*t*	*p*	Effect size
Mental load	Control group	2.86	0.59	0.84	16.78*	0.00	1.76
	Experimental group	2.02	0.37				

Mental effort	Control group	3.05	0.81	1.05	15.86*	0.00	1.60
	Experimental group	2.00	0.45				

Note. * $p < .05$. *SD* = Standard deviation, *MD* = mean difference

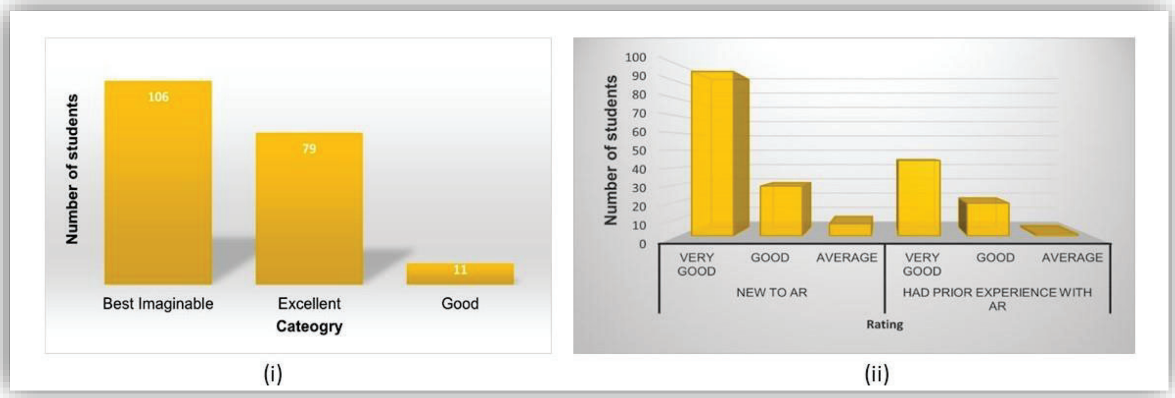


Figure 4: Summary of SUS data and Qualitative feedback from students

5. Discussions

The study assessed the effect of AR technology on improving students' 3-D visualization abilities in ED courses compared to conventional methods of studying ED. We created an AR application and encouraged the experimental group to study ED using the application while the control group studied ED using the traditional method. Four research questions were addressed in the study.

The first addressed the impact of AR-assisted ED learning on students' 3-D visualization skills. The findings demonstrated that, as compared to traditional approaches, AR significantly improved 3-D visualization skill in the ED. This result was aligned with earlier research where AR was used to improve visualization skill of students from architecture background (Escudero et al., 2016). In addition, they were able to visualize points and lines in various planes, which was not possible during classroom instruction.

The effect of AR technology in reducing cognitive load in ED tasks is the focus of the second research question. The study found that students who exercised an AR-based application experienced substantially lower intrinsic and extraneous cognitive load compared to those who used traditional instruction methods. This result surpassed previous research that showed AR-based learning can minimize extraneous cognitive load in multimedia science (Lai et al., 2019).

The third research question addressed the usability of AR application for ED course. The average SUS score obtained revealed that our application is user-friendly and appropriate to ED courses. Previous research evaluating the utility of AR has shown equivalent results, indicating that AR-based applications can be employed in ED classrooms (Wijaya et al., 2019; Martin-Gonzale et al., 2010).

The final research question focuses on student satisfaction with the AR application. As indicated in the results section, students who had prior experience with AR used the application with ease, as did those who were experiencing AR for the first time. The application's nature as a marker-based AR application allowed users to avoid the difficulties associated with marker-less AR applications (Wijaya et al., 2019).

6. Conclusions and future work

This study determined that AR-assisted learning in ED was able to enhance students' 3-D visualization skills. The results also showed that students who used AR to study ED experienced less cognitive load than those who used conventional methods. The application was subsequently evaluated using the SUS scale. It was also revealed that the application is user-friendly and that students can study ED using this application. In their response, students suggested that the software can be used as an alternative to Auto-CAD because it allows users to create custom designs. This turned out to be one of the limitations encountered by our application. In addition, the application was only compatible with handsets running the Android operating system and not iOS.

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