Smart Learning Environments

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Designing and evaluating an augmented reality system for an engineering drawing course

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Abstract

Currently, augmented reality (AR) is one of the emerging technologies which is being widely used in the education sector. In engineering drawing, AR has been implemented to enhance learners' spatial ability but not their conceptual knowledge yet. Therefore, this study aims to evaluate the effect of AR on engineering drawing students' learning performance. In this study, we developed an AR-based application EDINAR to learn engineering drawing concepts for undergraduate engineering students. The study included 392 first-year students from an engineering institution. The control group (N = 196) studied engineering drawing using traditional methods, whereas the experimental group (N = 196) used an AR-based engineering drawing application (EDINAR) to learn engineering drawing. One-way ANOVA was used to analyse the performances of both groups. The findings revealed that students studying engineering drawing with the help of EDINAR outperformed those using traditional approaches. In addition, we received positive feedback about the AR application from the experimental group about their learning experience. Based on these results, it is recommended to incorporate AR in engineering education to improve the learning performance and students' learning experience.

Keywords: Augmented reality, Engineering drawing, Learning performance, Marker-based AR, Spatial ability

Introduction

Engineering Drawing (ED) courses play an important role in Engineering Education (Lagenbach et al., 2015). They enable engineers to draw in detail, and read, comprehend, and interpret technical drawings which are necessary for technical exchanges (Bao et al., 2020). Additionally, the main objectives of ED courses are the cultivation of students' spatial skills, knowledge, design ability, creativity, and thinking skills (Liang et al., 2018).

Due to the rise of emerging engineering technologies, such as interactive designs as well as digital and intelligent manufacturing, several changes have been brought about in ED courses (Liang et al., 2018). The integration of Information and Communication Technology (ICT) in ED courses can enrich teaching and learning activities (Lanzotti et al., 2019). Particularly, the use of Computer-Aided Drawing (CAD) software for

2-dimensional and 3-dimensional drawings has transformed ED and enabled engineers to communicate using a formalized and common language (Lagenbach et al., 2015). CAD software refers to the use of computer systems to draw, modify, analyze, and optimize designs and drawings (Kosa & Karakuş, 2018). It is widely used to draw, generate, and validate drawings and designs while also reducing human effort and errors (Kosa & Karakuş, 2018; Rica et al., 2020).

Spatial and visualization skills are essential in ED (Tumkor and de Vries, 2015). Although the integration of CAD software can improve these skills (Rafi et al., 2006), it is not enough to effectively teach ED courses and assist students in comprehending complex concepts (Omar et al., 2019). In addition, due to time constraints and the large number of students in classes, students do not receive sufficient guidance and individual attention (Ariffin et al., 2017; Liang et al., 2018). Another determining factor that hinders students' ED education is the lack of hands-on experiences which leads to a disconnection between theoretical knowledge and practical skills (Bao et al., 2020). It is important for ED courses to address students' needs, maintain their interest and engagement, and meet their expectations (Shreeshail et al., 2020). Therefore, it is essential to enrich and reform teaching contents and methods of engineering drawing courses to develop engineers with strong scientific foundations, engineering skills, technological capabilities, and multidisciplinary knowledge. Furthermore, there is a clear need for a cultural shift (Vere et al., 2011), an increase in practical experiences (Jianqing & Zibin, 2015), and a focus on improving spatial and visualization skills (Marunic & Glazar, 2013; Sorby et al., 2013).

To transform and improve the effectiveness and quality of ED courses, new methods to teach ED, such as mobile learning, innovative case teaching, seminar teaching, and immersive learning, are being adopted (Liang et al., 2018). Augmented Reality (AR) is a technology that overlays digital information, such as images, videos, or interactive data, onto the real world. AR enhances the user's perception of the real world by adding digital elements to it (Azuma, 1997). Particularly, the use of AR as a means to enrich and improve ED courses is gaining ground, due to AR characteristics and potentials (Ali et al., 2017b). The integration of AR in engineering drawing courses offers numerous advantages. AR technology transforms static 2D engineering drawings into interactive 3D visualizations, enhancing students' understanding of complex geometries and spatial relationships in real-world scenarios (Danakorn Nincarean et al., 2019). It provides valuable real-time feedback by allowing students to overlay digital sketches on physical objects, accelerating the learning process. AR enriches the educational experience by adding interactivity, enabling students to engage with 3D models and simulate design changes, making learning more enjoyable (Martin-Gutierrez et al., 2012). Additionally, it fosters the development of essential skills such as digital design, 3D modelling, and technology integration, all crucial in the engineering field (Camba et al., 2014). Furthermore, AR promotes inclusivity by catering to various learning styles; visual learners benefit from dynamic visualizations, while tactile learners can interact with virtual 3D objects (Dorribo-Camba & Contero, 2013). AR also encourages critical thinking and creative problem-solving by encouraging students to experiment with different design iterations and evaluate outcomes promptly (Chin et al., 2019). Subsequently, the purpose of this study is to investigate the impact of augmented reality on the performance of students enrolled in an ED course. Specifically, the research questions (RQ) that it seeks to address are the following:

- RQ1—Can the AR-based application improve students' learning performance in engineering drawing course compared to the conventional instruction method?
- RQ2—Are there any significant differences in learners' performance for students of different achievement levels (based on PSVT-R scores) between the experimental and control groups?
- RQ3—How satisfied are the students with AR-based learning activity?

Literature review

Engineering drawing course

Modern engineers need to have advanced planning and drawing skills to be successful (Bertoline and Wiebe, 2005). ED is the universal language of engineers which can be applied in several domains (Rica et al., 2020) and contains detailed specifications concerning designs and products (Ali et al., 2022). Additionally, it is strongly connected with engineering practices, involves hands-on experiences, and is supported by rigorous theories (Mu et al., 2021). ED fosters higher-order thinking skills and prepares engineering students to propose effective solutions for real-world problems (Sharma et al., 2020). Hence, it is regarded as an important course in engineering science (Sharma et al., 2020).

Being able to draw, read, and interpret EDs efficiently is necessary for research and technical exchange (Bao et al., 2020) and exert significant impact throughout the design and production processes (Shreeshail & Koti, 2016). Therefore, ED courses aim at enabling students to learn the theory, methods, and tools to read and draw EDs. Moreover, they focus on cultivating engineers who have high-quality technical and practical skills, pursue innovation, can solve complex problems, follow the graphical language rules, and can convey their thoughts in a clear and comprehensible manner, so they can easily be interpreted and executed (Chang, 2012; Mu et al., 2022; Raffaeli et al., 2019). ED is differentiated from other engineering subjects as it requires spatial and visualization skills and is used as a means of graphical communication (Olkun, 2003; Sharma et al., 2020). The projection theory, which is the representation of 3-D objects on 2D media, as well as mechanical and basic drawing are fundamental components of ED which help students cultivate their critical thinking and reasoning skills, and convey their ideas (Gorgani and Pak, 2020; Jianqing & Zibin, 2015).

ED courses have been evolving from just using vellum paper, drafting boards, and hand tools to integrating 2D-CAD and 3D-CAD tools to address the problems faced by students when learning through traditional methods (Garland et al., 2017; Kösa & Karakuş, 2018). Various factors lead to students experiencing difficulties in ED courses. In their study, Ali et al. (2017a) pointed out that a significant challenge for students arises from their limited ability to visualize 2D representations and 3D objects. Serdar et al. (2013) also noted that this issue becomes more pronounced when dealing with complex concepts like orthographic and isometric projections. Students also experience problems imagining the space when they observe projection drawings containing 3D objects (Tsutsumi, 2004). Visualizing complex concepts or rare phenomena is another challenge that students face (Nordin et al., 2013). ED is characterized by hierarchical design meaning that the comprehension of one concept depends on the understanding of another (Yasin et al., 2012). As a result, the lack of visualization skills makes it more difficult for the students to learn and actively participate in learning activities when they do not understand the content being taught (Ali et al., 2022; Baronio et al., 2016). Bao et al. (2020) highlighted additional factors contributing to challenges in ED course. Such as, ineffective evaluation techniques, the presence of outdated and excessive content, along with a deficiency in impactful and engaging teaching methods, insufficient instructional hours, and limited hands-on learning opportunities.

Recent studies have explored the use of ICT tools to teach ED courses. Studies, such as (Jianqing & Zibin, 2015; Kösa & Karakuş, 2018), investigated the use of CAD software to transform traditional ED courses and improve teaching and learning activities. Their results showcased that CAD software can lead to increased learning outcomes when compared to traditional methods and allow students to get a better understanding of the concepts taught. Studies have also looked into novel ways to assess ED courses more effectively (Gorgani & Pak, 2020). Other studies explored the use of interactive multimedia (Widayana et al., 2020), web-based interactive 3D concept maps (Violante & Vezzetti, 2015), and e-book multimedia (Mujiarto et al., 2019). Their results showed that multimedia and interactive means can improve students' motivation and independence while also increasing their understanding of ED course concepts and helping them build effective mental representations of learning contents, thus, leading to better student performance. Studies have also examined integrating ICT tools to offer online ED courses. Particularly, the studies involved the use of Massive Open Online Courses (MOOCs) (Lanzotti et al., 2019), blended learning environments (Szeto & Cheng, 2016), and comparisons between online and traditional face-to-face ED courses (Mu et al., 2021; Raffaeli et al., 2019; Wang et al., 2019). According to their results, no significant differences were observed in terms of learning effectiveness. Besides the use of ICT, studies looked into the use of project-based learning (Mingxia, 2021) and problem-based learning (Ariffin et al., 2017; Shreeshail et al., 2020; Yasin et al., 2012) approaches to improve the efficiency of ED courses. These approaches led to increased students' engagement, learning achievement, critical thinking, and problem-solving skills. The use of immersive technologies, such as AR, is becoming more popular in teaching ED courses as it can bring about positive outcomes (Ali et al., 2017b).

Augmented reality and its effectiveness

AR is closer to the real physical environment in the "reality-virtuality continuum" (Milgram & Kishino, 1994). Aiming at enriching the physical environment that surrounds users, AR uses computational units to create digital objects and embed them in the real environment as it is perceived by the users in the appropriate time and space (Azuma, 1997; Lampropoulos et al., 2022; Thomas & David, 1992). AR uses different types of media, such as non-interactive, interactive AR, and interactive non-AR media, with interactive AR media being the most effective for educational purposes (Ali et al., 2017b). Moreover, AR applications can be categorized into triggered (e.g., projection-based, location-based, dynamic augmentation, and complex augmentation) and view-based ones (e.g., indirect augmentation, and non-specific digital augmentation) (Edwards-Stewart et al., 2016). Brito and Stoyanova (2018) explained that AR applications can be categorised into marker-based or marker-less, depending on whether they use markers or not. Marker-based AR relies on predefined markers like images or patterns to anchor digital content in the real world, offering precise and stable AR experiences. In contrast, markerless AR doesn't require markers and uses computer vision to track the environment, providing more versatility but potentially sacrificing precision (Cheng et al., 2017).

Due to its immersive nature and its ability to combine the real environment with digital environments, AR can be adopted and used in educational settings (Garzón et al., 2019; Lee, 2012). Moreover, AR supports learning theories that are based on constructivism, such as cognitive flexibility, case-based learning, simulations, and collaborative learning (Dunleavy & Dede, 2014). It supports hands-on practices, promotes students' innovative ability, affects their knowledge acquisition, and allows them to experience real-world scenarios and environments safely (Liang et al., 2018; Wu et al., 2013). Through AR, flexible and interactive learning environments that support the cultivation of vital critical skills (e.g., critical thinking, problem-solving, emotional intelligence, etc.) (Spiro et al., 2003) and improve students' emotions, creativity, and thinking ability (Lin et al., 2014) can be created. These environments have the potential to support multiple representations of objects, allow learners to develop cognitively flexible processing skills, and facilitate the comprehension of concepts from ill-structured knowledge domains.

Due to the benefits that AR can potentially yield, recent studies explored its use in ED courses. Ali et al. (2017b) conducted a systematic literature review to investigate the impact of AR on ED courses. Their findings demonstrated that AR was well-received by both students and teachers, increased students' visualization skills and comprehension of complex concepts, and improved the overall learning experience. AR can be a powerful tool for improving the spatial abilities of students by providing immersive, interactive, and personalized learning experiences that promote spatial understanding and problem-solving skills (Contero et al., 2012; Dünser et al., 2006; Martín-Gutiérrez et al., 2015). Serdar (2016) emphasized improving students' visualization and understanding of 3D objects from 2D views through the use of mixed reality technologies. Their results revealed that mixed reality applications can improve students' comprehension of complex concepts and allow students to observe objects from multiple angles and interact with them. Ali et al. (2017a) focused on addressing the problems that students face in ED courses through AR environments. Their results revealed that when using AR, students comprehended and combined 2D objects more easily. Zhang et al. (2021) explored the use of AR in engineering courses with an emphasis on collaborative assembly training. Learners evaluated the overall experience as positive and the application as easy to use. Although studies started to explore the viability of AR as an ED teaching tool, the need for more empirical studies to analyze the effect and potential of interactive and flexible AR applications in ED courses is imperative (Ali et al., 2017b). Additionally, it is essential to explore new teaching methods and approaches that will result in the transformation of the educational process and facilitate the learning of complex concepts within ED courses (Liang et al., 2018).

Within the current body of literature, several studies have initiated the investigation of Augmented Reality (AR) as a pedagogical tool for Educational Technology (ED) courses. Notably, Ali et al. (2017a) specifically evaluated the impact of AR on students' spatial abilities but did not extend the analysis to encompass its influence on learning

Table 1 Sample feedback provided by the subject experts

1. Arrange topics in fundamental order to expertise manner
2. Omit sphere part and auxiliary plane part
3. Projection of line is most important
4. Conic Section, projection of lines, and projection of planes are important topics
5. Suggested to include Isometric View contents
6. Visualization and handling large number of students in classroom, are most concerned issues in ED
7. The projection of a plane is more important compared to the projection of lines
8. Suggested that app could be helpful for students
9. According to demonstration of contents in ED is difficult with the help of slides, materials available on YouTube is sometimes insufficient

performance in ED courses. Our study endeavors to contribute to the field by addressing this notable research gap. Thus, our primary objective is to assess the effectiveness of AR in enhancing students' learning performance within the context of ED courses. Additionally, our research investigates the impact of AR integration on students' learning performance, considering variations in achievement levels.

Methodology

Research design and sample

In the first phase of the study, we conducted a pilot survey with fifty-three undergraduate engineering students to identify their difficulties in studying ED courses. The data were collected from an engineering college located in the eastern part of India. In addition, we consulted eighteen subject experts from an engineering institute to understand the challenges faced by the students in understanding some concepts in the ED course. These experts have more than 10 years of experience in teaching ED courses. Table 1 provides some of the feedback from the experts. In the survey, it was identified that some complex concepts such as cross-sections of solids and projections of lines, points, solids, and planes which the students faced difficulties in visualizing. We employed a true experimental design. It included 392 (Males = 291, Females = 101) students in total. These students ranged in age from 19 to 22 and were chosen from an engineering institution. The students were selected at random from the first-year Undergraduate engineering course. We used a random sampling technique for selecting students for the experiment. Both groups—the experimental group and the control group had 196 students each. While the control group continued to study ED using a traditional method, the experimental group used the AR application for ED to do so. Table 2 shows the demographic statistics of the students who participated in the study.

Design and illustration of augmented reality-based engineering drawing application

In this study, we used Unity[1] software to create an augmented reality-based engineering drawing application (EDINAR) to improve engineering drawing students' learning outcomes and motivation. With reference to suggestions by subject experts, the application was composed of seven modules: orthographic view, auxiliary plane, projection of solids,

[1] https://unity.com/

Table 2 Demographic details

Measure	Category	Number	Percentage (%)
Gender	Female	291	74.23
	Male	101	25.76
	Total	392	
Age (years)	19	116	29.59
	20	124	31.63
	Above 20	152	38.77
	Total	392	
Department (undergraduate)	Computer science engineering	134	34.18
	Mechanical engineering	83	21.17
	Electronics engineering	149	38.01
	Civil engineering	26	6.63
	Total	392	

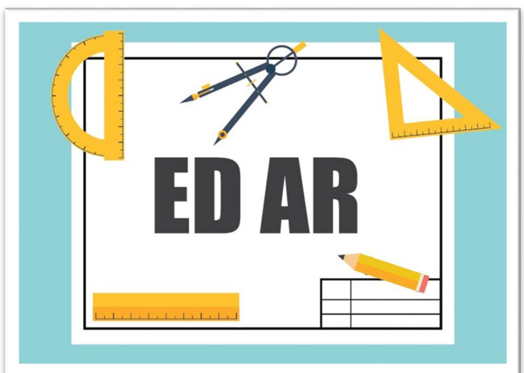

Fig. 1 Marker of EDINAR

projection of lines, projection of points, projection of planes and cross-section of solids. The user must point the in-device camera at the target image (see Fig. 1) to start using the application since it is a marker-based app. EDINAR begins with a list of the modules it contains (see Fig. 2). The user had to tap on one of these modules to open it. Then, 3D AR shapes will appear on the user's interface with various functions attached to them (Fig. 3). The application permits users to resize, rotate, and view shapes and planes from a variety of perspectives (front view, top view, back view, left view, right view and bottom view) (see Fig. 4). The user can also select a different shape from the available options. In projection modules, users could view objects in different planes and visualize them from various perspectives (see Figs. 3, 4). Users were instructed to follow self-paced learning for 1 week and explore all functions available in various modules in the given time. This application was Android-based and students were suggested to use smartphones supporting Android 8 and above.

In developing the application, guiding principles were drawn from the Cognitive Theory of Multimedia Learning (CTML) proposed by Mayer (2014). This theory, deeply embedded in cognitive science, offers insights into the mechanisms by which the human brain assimilates information from multimedia instructional messages.

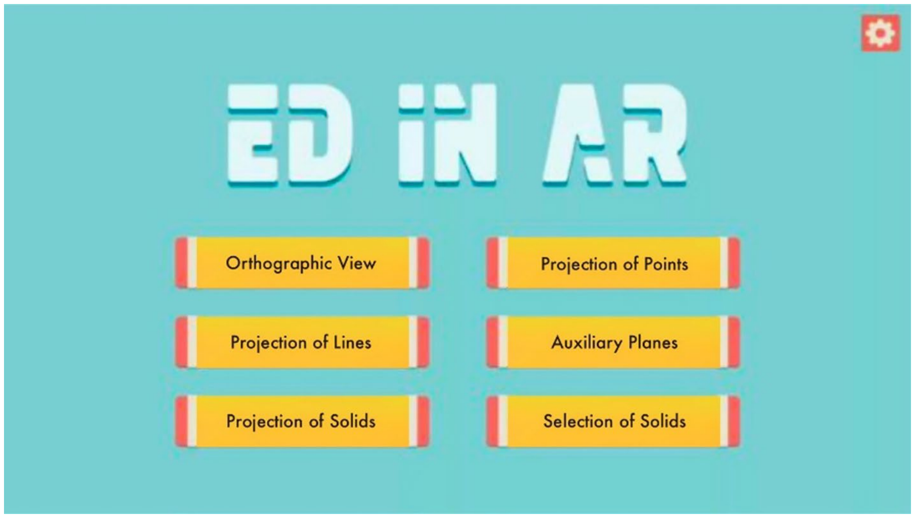

Fig. 2 Introduction scene

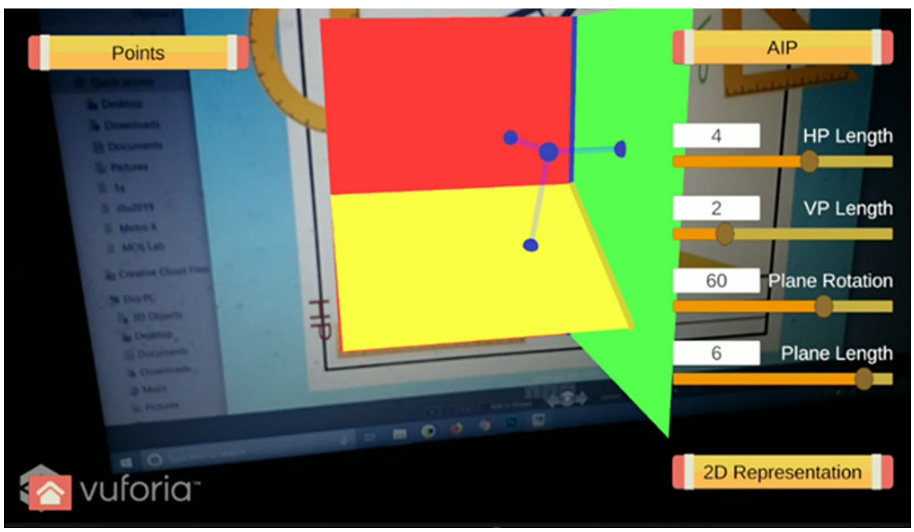

Fig. 3 Projection of points

The relevance of CTML in designing AR applications, particularly in educational contexts, has been emphasized by Sommerauer and Müller (2014). Their advocacy underlines the theory's utility in tailoring AR experiences in our study to align with learners' cognitive processes. The AR application in our study was developed by incorporating distinct principles of multimedia learning. Specifically, we integrated: (a) the multimedia principle, emphasizing enhanced learning from a combination of text and visuals over text alone; (b) the coherence principle, ensuring the exclusion of extraneous materials not pertinent to the subject matter; (c) the redundancy principle, highlighting the effectiveness of learning from graphics and narration over a combination of graphics, narration, and on-screen text; (d) the signaling principle, which focuses on drawing learners' attention to crucial elements for improved learning; and

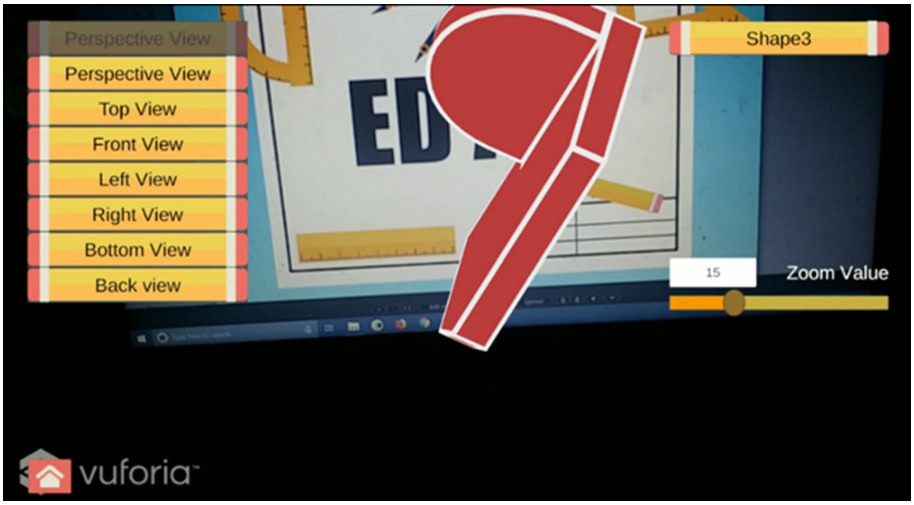

Fig. 4 Orthographic projection

(e) the segmenting principle, advocating for the breakdown of complex topics into manageable subtopics for better comprehension., 4). Users were instructed to follow self-paced learning for 1 week and explore all functions available in various modules in the given time. This application was Android-based and students were suggested to use smartphones supporting Android 8 and above.

Instruments

Pre-test and post-test

The researchers constructed pre-tests and post-tests to assess the student's learning performance in the control group (CG) and the experimental group (EG). These tests were used to assess the ED knowledge of students. We ensured that questions in the test were relevant to the course material. Both the pretest and posttest were comprised of 20 multiple-choice questions and a group of five domain experts were consulted for the validation of the test items. The standard of questions in the pre-test and the post-test were similar (see Fig. 5). The overall Cronbach's α values for both the pre-test and post-test were above 0.7, which is acceptable (Barrett, 2001). Students in each group were given a maximum of 30 min to complete the pre-test and post-test.

Revised purdue spatial visualization tests: visualization of rotations (Revised PSVT: R)

The Revised Purdue Spatial Visualization Tests: Visualization of Rotations (Revised PSVT: R) (Yoon, 2011) is an updated version of PSVT: R (Bodner & Guay, 1997). The Revised PSVT: R is a tool for measuring spatial visualization ability in three-dimensional mental rotation in individuals over the age of 13. Maeda et al., (2013) used this test to assess the spatial ability of first-year undergraduate engineering students. Therefore, we found Revised PSVT-R suitable for our study. The psychometric tool has two practice questions and then 30 test questions. The test questions consisted of 13 symmetrical and 17 asymmetrical 2-D isometric drawings of 3-D objects. The participants were given a maximum of 25 min to complete the PSVT: R test.

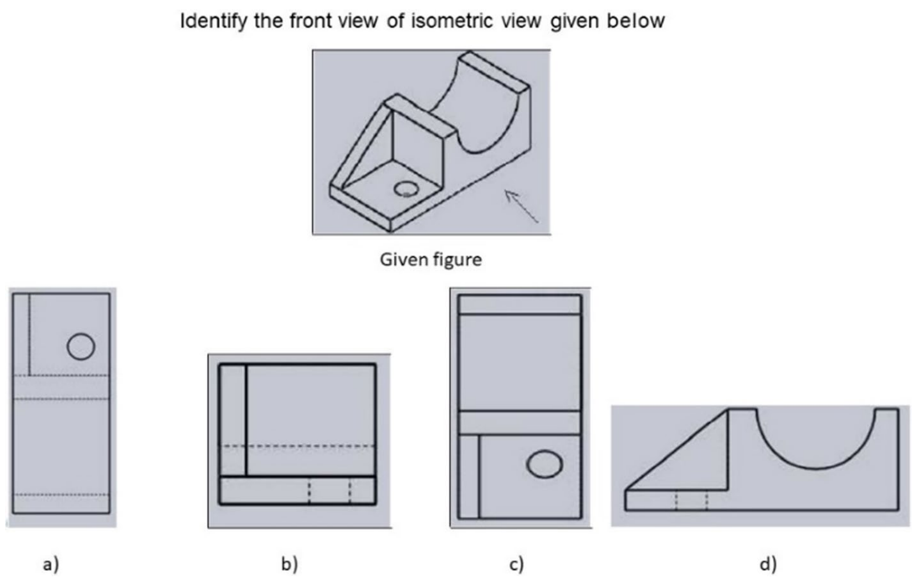

Fig. 5 Examples of questions included in the pre-test and post-test

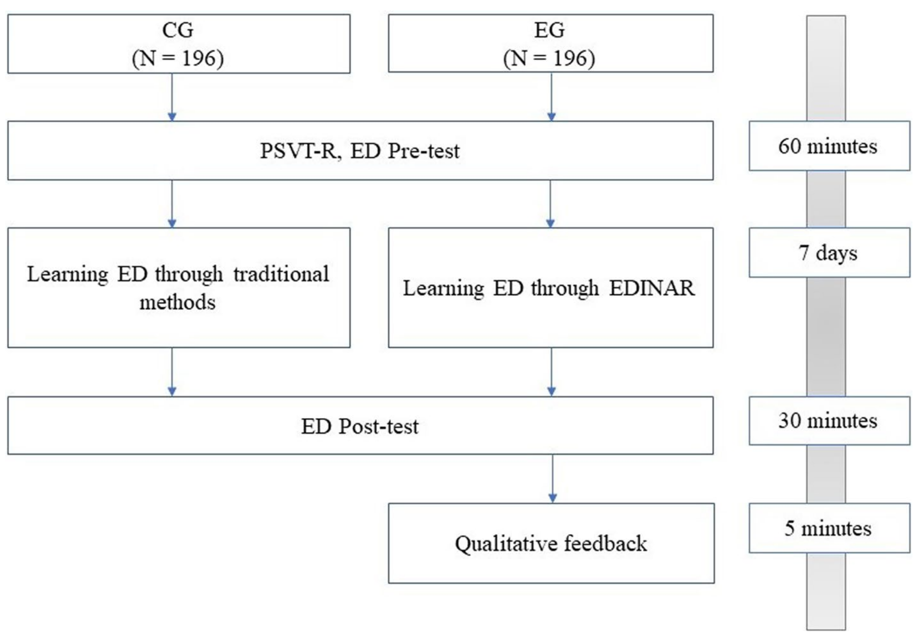

Fig. 6 Experiment procedure

In addition to these instruments, we employed a questionnaire to get student feedback about their experience with EDINAR (see Appendix A).

Procedure

Figure 6 demonstrates the experimental procedure of the study. The experiment consists of three stages: (a) initially both groups were required to complete the PSVT-R test, and then they were asked to complete the pre-test within the allotted time, (b) students in the experimental group were instructed to use the EDINAR to study ED for a week,

Table 3 One-way ANOVA results of pre-test and post-test for each group

	Group	Mean	SD	F-value	*p*
Pre	Experiment Group	12.80	4.04	0.001	0.96
	Control group	12.78	3.86		
Post	Experiment Group	18.07	3.84	154.55*	0.00
	Control group	12.85	3.24		

*$p < .05$. SD = Standard deviation

simultaneously students in the control group were asked to study ED using conventional methods and (c) both groups were asked to complete the post-test. Thereafter, students in the experimental group were asked to give their feedback regarding the AR application they used to study ED.

Data analysis

Descriptive statistics and inferential statistics were used to analyze the collected data. We employed one-way ANOVA analysis to examine the differences in learning performance between the experimental group and the control group. Skewness and kurtosis were computed to test the data's normality. All the variables' skewness and kurtosis values fall within the recommended ranges of |3| and |10|, respectively (Kline et al., 1999). All analyses were carried out using the Statistical Package for the Social Sciences, version 21 (SPSS 21).

Results

Learning performances

A one-way ANOVA was conducted on pretest scores to examine whether there was a significant difference in students' knowledge of ED before the intervention. Similarly, we conducted a one-way ANOVA on post-test scores to evaluate whether there was a statistically significant difference in learning performance between groups after the intervention. The results of our study are shown in Table 3, which includes the means and standard deviations of the scores obtained by the groups on the pre-test and post-test. In the pretest, the mean value and standard deviation were 12.78 and 3.86 for the control group, and 12.80 and 4.04 for the experimental group, respectively. In the post-test, the mean value and standard deviation were 12.85 and 3.84 for the control group, and 18.07 and 3.24 for the experimental group, respectively. The findings show that there was no significant difference in pre-test scores between the control group and the experimental group, however, there was a significant difference in their post-test scores. (pre-test: $F = 0.001$, $p > 0.05$, post-test: $F = 154.55$, $p < 0.05$).

In addition, we also performed a one-way ANOVA on the control group and experimental group's learning gains. The mean score and standard deviation of the control group were respectively 5.41 and 4.10. The experimental group had a mean score of 8.20 and a standard deviation of 4.97, respectively (see Table 4). The findings in Table 4 show that there was a substantial difference between the experimental group and the control group in terms of learning gain ($F = 36.65$, $p < 0.05$).

Table 4 One-way ANOVA results of learning gain for each group

Group	Mean	*SD*	*F*-Value	*p*
Experiment Group	8.20	4.97	36.65*	0.00
Control group	5.41	4.10		

* $p < .05$. *SD* = Standard deviation

Table 5 One-way ANOVA results of learning performance for each group based on their achievement levels

	Achievement level	Group	*N*	Mean	*SD*	*F*-value	*p*
Pre-test	High	EG	124	10.09	4.83	1.56	0.41
		CG	121	10.88	5.07		
	Average	EG	14	10.50	5.60	0.95	0.33
		CG	12	12.55	4.60		
	Low	EG	58	9.42	4.79	1.20	0.27
		CG	63	10.40	4.96		
Post-test	High	EG	124	17.23	4.77	72.04*	0.00
		CG	121	12.21	4.40		
	Average	EG	14	19.00	1.04	109.35*	0.00
		CG	12	14.66	1.43		
	Low	EG	58	18.10	3.07	75.00*	0.00
		CG	63	13.45	2.73		

*$p < .05$. *SD* = Standard deviation

Students in both groups were assigned to different achievement levels based on their PSVT-R test scores (Bodner & Guay, 1997). Low achievers were students who received less than 10 marks in the PSVT-R test, average achievers were those who received equal to 10 marks in the test, and high achievers were those who received more than 10 marks in the test. Table 5 depicts the outcomes of the participants' learning achievement based on the various achievement levels between the pre-test and post-test for both groups. We found that there were no significant differences in the pre-test performance of the students across the levels (high: $F = 1.56$, $p > 0.05$, average: $F = 0.95$, $p > 0.05$, low: $F = 1.20$, $p > 0.05$) (see Table 5). In contrast, there was a significant difference in post-test learning performance across the groups for all levels of students (high: $F = 72.04$, $p < 0.05$, average: $F = 109.35$, $p < 0.05$, low: $F = 75.00$, $p < 0.05$) (see Table 5). The experimental group's high achievers had a mean and standard deviation of 17.23 and 4.77, whereas the control group's high achievers had a mean and standard deviation of 12.21 and 4.40. The average achievers in the experimental group had a mean and standard deviation of 19.00 and 1.04, while the average achievers in the control group had a mean and standard deviation of 14.66 and 1.43. Low achievers in the experimental group had a mean score of 18.50 and a standard deviation of 3.07, whereas those in the control group had a score of 13.45 and a standard deviation of 2.73.

Students' experience with AR technology in engineering drawing course

The qualitative feedback obtained from the experimental group is labelled into five categories (see Table 6). In the experimental group consisting of 196 students, it was

Table 6 The students' feedback regarding EDINAR

	Comments	Responses (in %)
Usefulness of AR	Find AR useful	95.40
	Didn't find AR useful	0.04
Positive factors of EDINAR	AR has transformed the way we study ED	15.81
	This application is a good substitute for AutoCAD	18.36
	AR has assisted in the visualization of complicated concepts in the ED	28.57
	In addition to video games, education is another potential application of augmented reality	6.63
Negative factors of EDINAR	None	82.14
	There were challenges with the app's functionalities	8.16
	The application's UI interface was not good	3.06
	Some ED topics, such as cross-section, were inadequate. As explained in the application	6.63
What EDINAR provides	Helpful for first-year students taking an ED class	46.93
	Could be used in the classroom by teachers to teach ED	24.48
	This application would benefit undergraduates in the Civil and Mechanical Engineering departments	28.57
Recommendation to use EDINAR	Yes	98.97
	No	

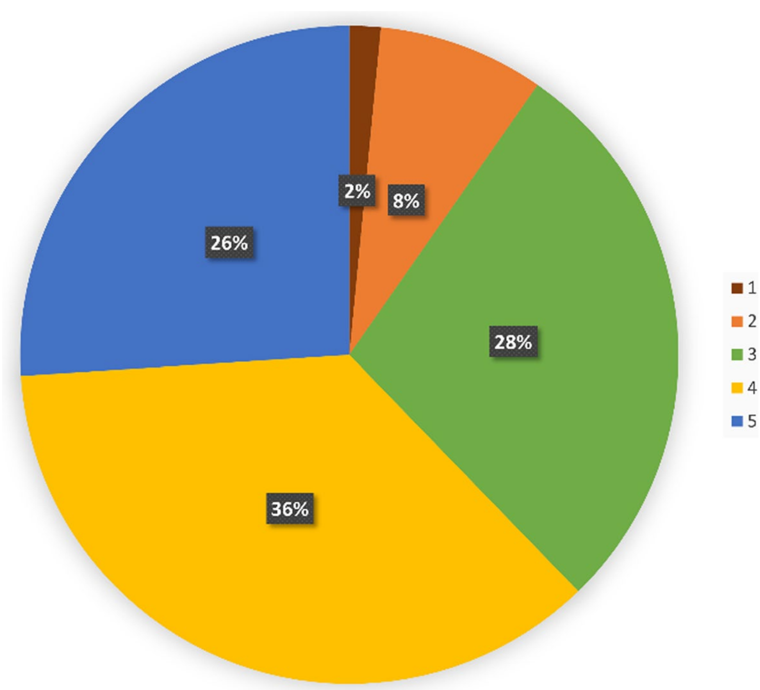

Fig. 7 Students' rating for EDINAR

noted that 71 students gave the application a rating of 4 out of 5, while 51 students awarded it the highest rating of 5 out of 5 (see Fig. 7). It was also found that very few students were not happy with the application as shown by their rating. Students stated that EDINAR may serve as a suitable substitute for AutoCAD in laboratory classes as well. A significant number of students believed that, as a result of EDINAR, they were better able to visualize complex concepts of the ED course.

Although some of the students reported having trouble using EDINAR's functions and disliked its user interface, a great number of students liked the application and were able to finish all the topics without difficulty. A small number of students believed that EDINAR did not properly explain certain concepts, such as the cross-sections of solids and planes. Students stated that the application is helpful for first-year undergraduates who will be studying ED for the first time. They also agreed that teachers could also use this application to teach ED in the classroom. According to students, EDINAR would be valuable for undergraduate students in the Civil Engineering and Mechanical Engineering departments. The majority of students expressed an interest in recommending EDINAR to their peers.

Discussion and conclusion

This study examined the effect of AR technology on students' learning in an ED course as compared to conventional methods of studying ED. We developed an AR application and included the complex concepts taught that were identified in the pilot study related to the ED course. Three research questions were addressed in this study—the first one deals with the effectiveness of AR-assisted ED learning on the performance of the students. These outcomes can be attributed to the AR application's features that enabled users to visualize complex shapes and their cross-sectional components in 3-D form from various perspectives. The results revealed that in comparison to conventional methods, AR significantly improved students' learning performance. This result is consistent with earlier research indicating that AR can improve learning outcomes (Ali et al., 2017a; Liou et al., 2016; Murthy et al., 2015). Engineering drawing often involves complex concepts and AR provides a visual representation with the multi-sensory experience of these 3-dimensional concepts, making it easier for students to understand and retain information (Ali et al., 2017a). In addition, AR facilitates active learning, where students are more directly involved in the learning process, leading to improved performance (Adi et al., 2022).

The second research question investigated whether there were statistically significant differences between the experimental and control groups in terms of students' performance with varying achievement levels (based on PSVT-R scores). In the post-test, it was observed that the experimental group did better than the control group, and this was true regardless of the achievement levels of either group. The simplification of complex ED course content into 3-D forms with improved visualization and features such as rotation and zoom in the AR application facilitated students of varying spatial abilities to achieve better results in the post-test. The high achievers in the experimental group did significantly better than those in the control group. This result is in line with past research indicating that AR can enhance the learning of students of all achievement levels (Bhagat et al., 2021).

In the last research question, we analysed the feedback received from the students to determine their perspective and application of AR in education. Students agreed that AR-assisted learning is useful for courses that cover complex topics, such as ED. Over half of the students found satisfaction in the engaging and interactive aspects of the AR application, as evidenced by the ratings they gave. This aligns with findings from prior studies (Dünser et al., 2012; Tombi & Rambli, 2013). Some students encountered difficulties in positioning their devices correctly with the markers to accurately display the 3-D models on the screen. This is a commonly encountered drawback experienced by users of marker-based AR applications (KB & Patil, 2020). Students' feedback indicated a significant increase in their visualization because of the use of augmented reality in their learning, which was supported by prior research (Martin et al., 2015). The projection of points and lines in different planes and quadrants is one of those difficult topics that have been simplified by using AR. Students noted that the AR application was beneficial in learning the projection of points and lines, an aspect they found challenging to grasp in the traditional classroom setting. Additionally, the AR technology more effectively demonstrated orthographic projection, the projection of solids, and their cross-sectional parts, as reflected in their feedback. Feedback from students indicated that breaking down complex topics of ED into subtopics made it easier for them to grasp the content. The predominance of 3-D images over text in the AR application further clarified their understanding. Additionally, they noted the minimal repetition of content within the application, aiding them in concentrating more effectively on pertinent material. These results are consistent with prior research findings (Bhagat et al., 2021; Zambri & Kamaruzaman, 2020).

Limitations and future work

The study has some limitations. First, the students were not permitted to draw while using the EDINAR. They could only explore the shapes and features provided in the application. Second, EDINAR lack a feature that allows students to create customized structures like pipes, buildings etc. using the basic shapes that were available in the application. Third, EDINAR is available only for Android users and not for iOS users. Another limitation of the study was the disproportionate inclusion of fewer female participants compared to a larger number of male participants, which could have introduced bias into the research findings. While acknowledging the benefits of using AR in the context of an ED course, it's important to recognize that it cannot replace the hands-on experience, which is a crucial aspect of learning in ED courses. In future, we intend to incorporate an assessment experience into our application so that teachers can utilize it as an interactive assessment tool for an engineering drawing course. The application also requires a feature that enables tracking of usage and collection of log data.

We also aim to include a mechanism in our application that would allow students to construct shapes with varied dimensions based on their requirements. Including the features listed above in our application would make it more dynamic, allowing students to learn ED topics more effectively. Additionally, we aim to explore various other media forms for teaching ED, which could be evaluated alongside AR for the ED course. This expansion is motivated by the fact that in this study, the traditional content for the ED course was limited to text and image-based slides. Finally, in order to provide users with more time to learn the course using our application, we will lengthen the intervention period.

Appendix A: Open ended questions

1. Do you have any previous experience of using AR app? (Yes, No)
2. How much would you rate the EDINAR? (1,2,3,4,5)
3. Did you find the EDINAR useful? (Yes, No, Maybe)
4. What did you like about the EDINAR?
5. What are the difficulties you faced with the functions of EDINAR?
6. What can we do to improve the User Interface of EDINAR?
7. Any suggestions about the overall App that needs to be improved?
8. What goals or benefits are you seeking through the use of EDINAR?
9. Would you like to motivate your friends to use EDINAR? If yes/no, why?
10. Do you have anything else you would like to share about EDINAR?

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Author contributions
AST, KKB: conceptualization; AST, KKB: methodology, formal analysis, investigation, data collection, data curation, writing original draft; AST, KKB, GL: writing – review & editing; KKB: funding acquisition. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study complied with all the ethical guidelines for surveys with human participants. All participants were informed of the purpose and procedures beforehand, and asked to submit written informed consent. They were free to quit at any time.

Competing interests
The authors declare that they have no competing interests.

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