Journal of Learning and Teaching in Digital Age, 2022, 7(2), 160-174
https://dergipark.org.tr/en/pub/joltida
ISSN: 2458-8350 (online)

Research Paper

The Effects of Augmented Reality in the Technical Drawing Course on Engineering Students' Spatial Ability and Academic Achievement

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ARTICLE INFO

Received: 07 November 2021
Revised: 31 March 2022
Accepted: 01 April 2022

Keywords:
Augmented reality
Spatial Ability
Virtual environments
Technical drawing

doi:10.53850/joltida.1020075

ABSTRACT

The purpose of this study is to investigate the effects of Augmented Reality (AR) intervention on students' spatial skills and academic achievement. The study was conducted in a freshman technical drawing course at Mechanical Engineering Department. An exploratory quasi-experimental method was used for the study. The study was conducted in two groups (Experiment-Control) as a quasi-experimental pre-post design. The pre-test results were used only to determine the control group and the experimental group. The research process was conducted within a four-week experimental period, including a one-week pilot study. The researchers and lecturers who are recognised experts prepared the instruments. The drawings of the experimental and control groups were evaluated using the evaluation criteria prepared by the two expert lecturers of the course. In the evaluation, two types of scores were given to the students, namely "Academic Achievement Score" and "Spatial Ability Score". Using ANOVA, the effects of AR intervention on students' spatial skills and academic performance were examined over three experimental periods. There was a significant main effect for both groups with a large effect size ($\eta 2$=.253). However, it was found that there was no significant effect between the control group and the experimental group on spatial skills. However, it was found that there was a significant interaction effect providing the interaction between time and group on spatial abilities. In addition, no statistically significant difference was found between the academic performance of the experimental group and the control group and no significant difference was found in the weekly measurements of the groups. It was suggested that AR applications are very useful for students' spatial skills in technical drawing.

INTRODUCTION

Despite the increasing importance and diversification of technological materials used in education in recent years, printed materials are still widely used (Aydın, 2005; Cumaoglu et al., 2013; Hartman, et al., 2019). Printed materials have proven to be an indispensable part of the educational environment mainly because of their cost-effectiveness, portability, and conventionality (Fung, 2005; Özdemir, 2010; Sahin, et al., 2016; Backfisch, et al., 2021). However, some topics, concepts, and visuals cannot be taught through printed materials. For example, two-dimensional printed materials cannot explain certain abstract ideas and correct misconceptions (Pekdağ, 2010; Tian, et al., 2021). Technology always tries to overcome such problems by providing convenience and abundance of information to students. Educational technologies help students to be active outside the classroom and help them to learn better through technologies such as three-dimensional (3D) instructional materials. Students gain a better understanding of the concepts they are studying and make connections to real life situations (Çağıltay, 2016).

The widespread use of technology in the laboratory environment has ushered in a new era in engineering in recent years, with virtual laboratories, remotely controlled robotic systems, and virtual simulation environments being used extensively in education (Feisel & Rosa, 2005; Chi et al., 2013; Menezes et al., 2016; Sing et al., 2019). Augmented reality (AR) is an innovative technology that will help shape several fields of study, especially engineering, as well as the educational methods used in different sectors (Borrero & Marquez, 2011; Dini, et al., 2015; Enzai, et al., 2021). AR applications offer solutions to some major problems prevalent in engineering education, such as the lack of practice and the transformation of abstract ideas into tangible reality (Liarokapis et al., 2004; Chi, et al., 2013; Li, et al., 2018). Duenser, Steinbuegl, Kaufmann, and Glueck (2006), for example, identified the lack of hands-on practice and the abstractness of experimental environments as the main causes of problems in engineering courses that focus on drawing, modeling, and design. Lectures based on theoretical facts and the use of two-dimensional (2D) visual materials make it difficult for students to understand the content of engineering courses (Rafi, Samsudin, & Ismail, 2006; Fakhry, Kamel & Abdelaal, 2021). It is claimed that these problems also exist in engineering drawing courses offered in mechanical engineering departments (Usta, 2015; Duenser et al., 2006).

In Turkey, technical drawing education goes through certain phases. Generally, students first start by making two-dimensional drawings on paper and then they can transfer these drawings into isometric projections with three dimensions using drawing equipment. Following the drawing on paper, students draw the given models on the computer using a drawing program such as

AutoCAD or SolidWorks (Peng, 2011). From this point of view, students have problems in visualizing and modeling 3D objects using 2D surfaces (Rafi et al., 2006; Fakhry, Kamel & Abdelaal, 2021). This problem negatively affects students' academic performance and attitude towards the course (Martin-Gutierrez, Guinters, & Perez-Lopez, 2009; Pejic, et al., 2014; Marinakis, et al., 2021).

The development of Spatial Abilities (SA) for engineering students is closely related to success in their future careers (Miller, 1996; Sorby, 1999; Ada'nez & Velasco, 2002; Kwiatek et. al, 2019). McGee (1979) asserts that factorial research since 1930 demonstrates the existence of two types of spatial abilities (visualization and orientation). McGee (1979) also pointed out that genetic, environmental, hormonal, and neurological variations can affect SA test performance (McGee, 1979). On the other hand, many researchers have found that SA consists of 5 important elements. These elements are spatial perception, visualization, mental rotation, spatial relations, and spatial orientation (Gluck & Fitting, 2003; Linn & Petersen, 1985; Maier, 1996).

SA (Spatial Ability) is used in engineering, mathematics, geometry, chemistry, biology, and physical education (Maier, 1996; Hartman & Bertoline, 2005; Gómez-Tone et al., 2020). SA is related to the spatial thinking skills needed to create drawings and models (S. A. Sorby & Baartmans, 2000; Morosi et al., 2018; Kim & Irizarry, 2020). Students can overcome the problems they face in technical drawing classes if they are provided with the necessary materials to improve (Majoros and Neumann, 2001; Witmer, Baily & Knerr, 1996; Shelton & Hedley, 2002; Spasova & Ivanova, 2020; Marinakis et al., 2021).

The technologies of AR, which first appeared in the 1960s and have been used in education since the mid-1990s, play an important role in this context. AR is defined as a technology in which 3D virtual objects are integrated into a real 3D environment in real time, providing users with interactive and augmented content (Azuma, 1999; Carmigniani et al, 2011; Billinghurst, Clark & Lee, 2015; Akkuş & Ozhan, 2017). Course materials developed with the technology of AR enable interaction between the learner and the material and make the learner an active participant by engaging the learner's interest, motivation, participation, and effort (Nicholson, 2005). In addition to the interactive learning environment, these materials create a colorful learning environment that facilitates students' understanding of abstract concepts and helps them retain their knowledge longer (Azuma, 2001; Cipresso et al., 2018). AR enables the implementation of various experiments in a virtual environment that cannot be realized in real life due to either high cost or inaccessibility (Küçük, 2015).

In summary, the applications of AR are known to have made important contributions to educational environments and processes, and much research has been conducted on its general role in engineering education (Ong & Shen, 2009; Martin et al., 2011; Wu, Lee, Chang & Liang., 2013; Berkemeier, et al., 2019). This research, dedicated to AR technology, can help increase the efficiency of this novel and promising interdisciplinary field of study that draws on educational technologies and other fields. The reason for this study is to see that AR can be used in drawing lessons in the field of engineering and what its effects might be. Conducting the study will also shed light on the work to be done in this area. The fact that there are not many publications on the use of AR in the field of technical drawing is one of the reasons for this study. Therefore, this study investigates the effectiveness of an AR application developed for the technical drawing course in engineering education.

The Purpose of the Study

The overall objective of this study is to investigate the effects of the intervention of AR on students' spatial skills and academic achievement in the technical drawing course offered in the first year of Mechanical Engineering Department. Thus, the study seeks answers to the following questions:

- Does the use of the AR application in the technical drawing course have an impact on students' spatial skills?
- Does the use of the AR application in the technical drawing course have an impact on students' academic performance?

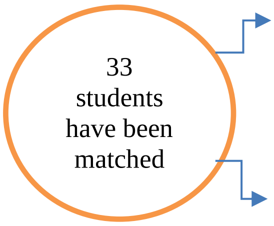
METHOD

Research Model

The posttest control group design (a type of quasi-experimental design) was used as research model. Two instructors who are content experts determined the three models to be drawn each week. While these models were presented to the experimental group in 3D in the lab through the AR application, students in the control group received only paper-based materials. Each week, the instructors evaluated the drawings made by the students in each group using the same rubric and recorded the scores, which were used as quantitative data.

The pretest, conducted to determine if the experimental and control groups are the same, is one of the most important components of a quasi-experimental research design (Ross, Morrison & Lowther, 2005). This study was conducted halfway through the spring semester. Therefore, participants' midterm exam scores were used as a pretest to compare groups. The posttest control group design is used to test a quantitative hypothesis by determining the differences between the mean scores of the experimental and control groups (Fraenkel & Wallen, 2003). The experimental and control groups were given posttests at the end of the experiments each week. The research design is shown in Table 1.

Table 1. Research Design



Groups	Group Formation	Task	Posttest
E 17 Students (**E**xperimental Group)	**M**	**X** Technical drawing using AR	**O** (Spatial Ability and Achievement Test)
C 16 Students (**C**ontrol Group)	**M**		O (Spatial Ability and Achievement Test)

M: Matching, **X**: Experiment, **O**: Posttest

Research Group

The study group consisted of first-year students taking the Engineering Technical Drawing Course at the Department of Mechanical Engineering, Malatya Inonu University. Random sampling method was preferred when creating research groups. Since both groups were randomly distributed in the study, it was assumed that the groups were equal and no intervention was made. As the sample size is 33 students, the experiment group consisted of 17 students and the control group 16 students.

Development of AR models

In this study three AR applications were developed to be used in the technical drawing course. QR code images were used to enable successful detection and tracking. This is because some studies in the literature have shown that when QR codes are used in image-based AR applications, they can be more easily tracked by imaging systems (Kan, Teng & Chou, 2009; Walsh, 2010). So, a free QR -code generator was used to create a custom QR -marker for each AR -application to be used in the experiment. QR -codes and their variations are commonly used in AR -applications because they work under different lighting conditions, the algorithms used in the software or software kit are quickly recognized, and they are easy to calibrate (Nikolaos & Kiyoshi, 2010).

Procedure

After identifying and resolving the problems encountered during the pilot implementation, the authors began the actual experiment, which lasted 3 weeks and consisted of 33 students in the experimental and control groups. The experiment was conducted within the weekly course hours. The experimental procedure of the study is shown in Figure 1.

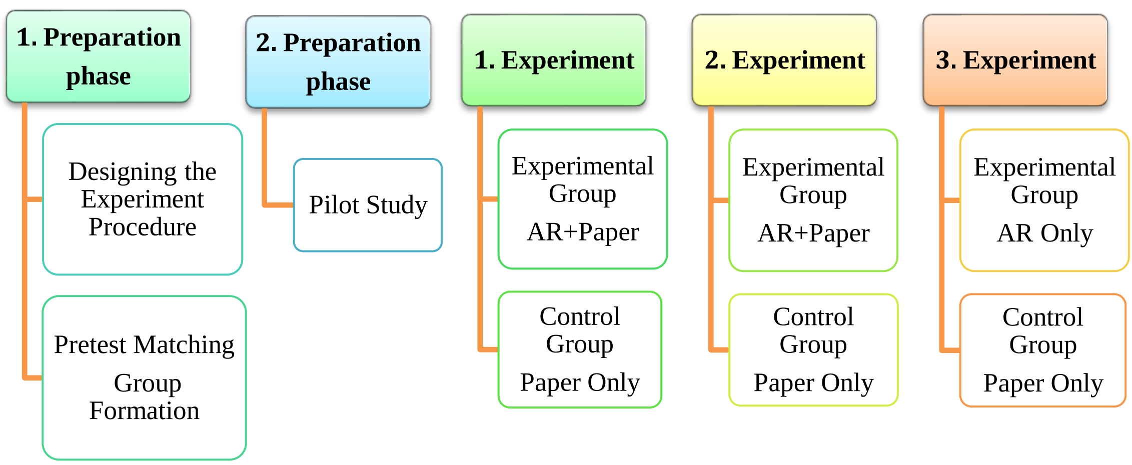


Figure 1. Experimental procedure

While students in the experimental group attended classes in the computer lab using the AR applications, students in the control group attended classes in the classroom. During the four-week experimental period, some students from both groups were absent; therefore, the experiment was conducted with 14 students in each group. The work plan for the experimental and control groups is shown in Figure 1. In the first week, preparations for conducting the experiment were completed and the procedure was designed.

In the second week, the grades that the students had previously received in the technical drawing course were evaluated and the groups were formed accordingly. Then, in the first two weeks of the experiment, the students in the experimental group received both a AR application and a printed solid form of the model they were to draw. In the third week, they received only the AR application of the model and were asked to make a drawing using this application. The control group received only the solid model on the printed paper of the model to be drawn during the 3-week implementation period. Students in both groups took 30 minutes to practice each week.

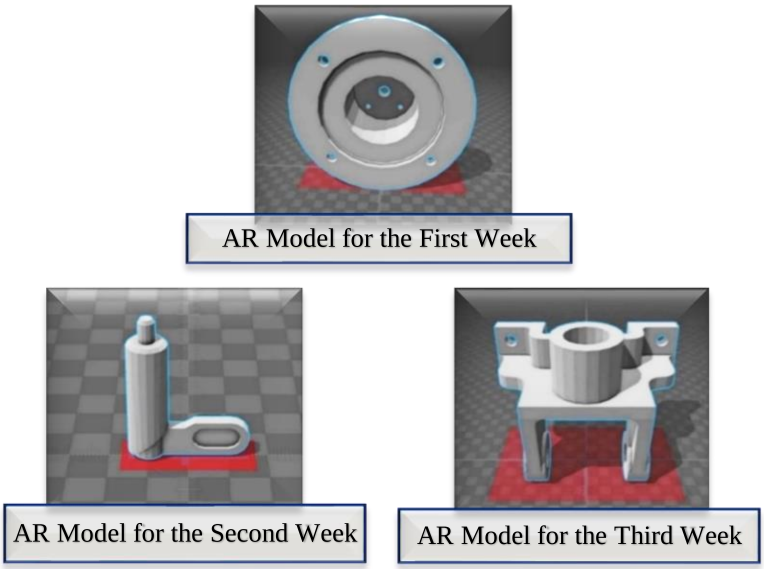


Figure 2. 3D models which used in this experimental study

During the three-week implementation, the students in the control group were provided only with a solid model printed on paper. The students in both groups were given a total time of 30 min to work on the drawings under the supervision of course the researcher and lecturers. We were not able to conduct the experiment in consecutive weeks because of exams and public holidays. There was a one-week interval between the 1st and 2nd weeks of the implementation, a two-week interval between the 2nd and 3rd weeks. Below are some photos of the control group students taken during the three-week implementation process in the laboratory (see Figure 3).

Figure 3. AR application laboratory images - Experimental group

Instruments

The instructors determined the drawing models that would be used to assess the students' performance and spatial skills. The drawing sheets contained models of progressively increasing difficulty (from easy to difficult) and were the main instrument for data collection. The spatial skills that students demonstrated in the drawings they made in class were the instrument for data collection after the three-week experiment. The drawing paper had four sections (see Figure 4). Students had to draw the model from three perspectives (front, side, and top) in the appropriate section. The students in the experimental group were to write their opinion about the function, advantages and disadvantages of the developed application in the bottom right section of the paper.

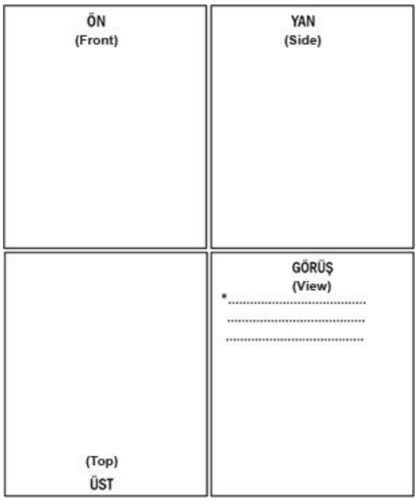


Figure 4. The sample of drawing paper

The researcher and the two instructors designed a SA test for the students. Then, they designed rubrics to evaluate the students' drawings in the experimental and control groups each week. In other words, the same scoring criteria were used to score each experiment.

In the literature, there a lot of SA tests were developed and used by researchers (Kelly *et al*., 2014). Kelly, Branoff and Clark (2014) have stated that MRT, MCT and PSVT: VR tests are top three preferred SA tests. The SA test that used in this paper was developed by them to PSVT: VR (Purdue Spatial Visualization Test: Visualization of Rotations) and DAT: SR(Bennett & Seashore, 1973) tests and piloted the application in the first week and fixed the errors. PSVT: VR SA Tests were used in engineering graphics education and visualization researches (Basham & Kotrlik, 2008; Milne, Morris, Katz, Covill, & Elton, 2014; S. Sorby, Nevin, Behan, Mageean, & Sheridan, 2014; S. A. Sorby, 2009).

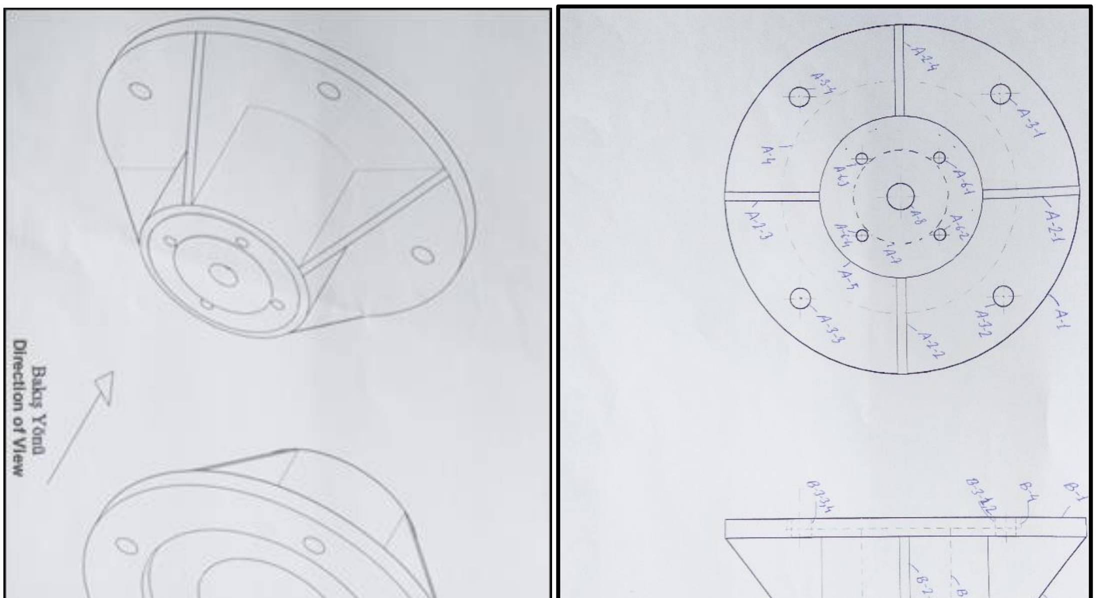


Figure 5. First week 2D Model (on left) and its rubric (Academic achievement and Spatial ability scores) to be used in the assessment of each experiment

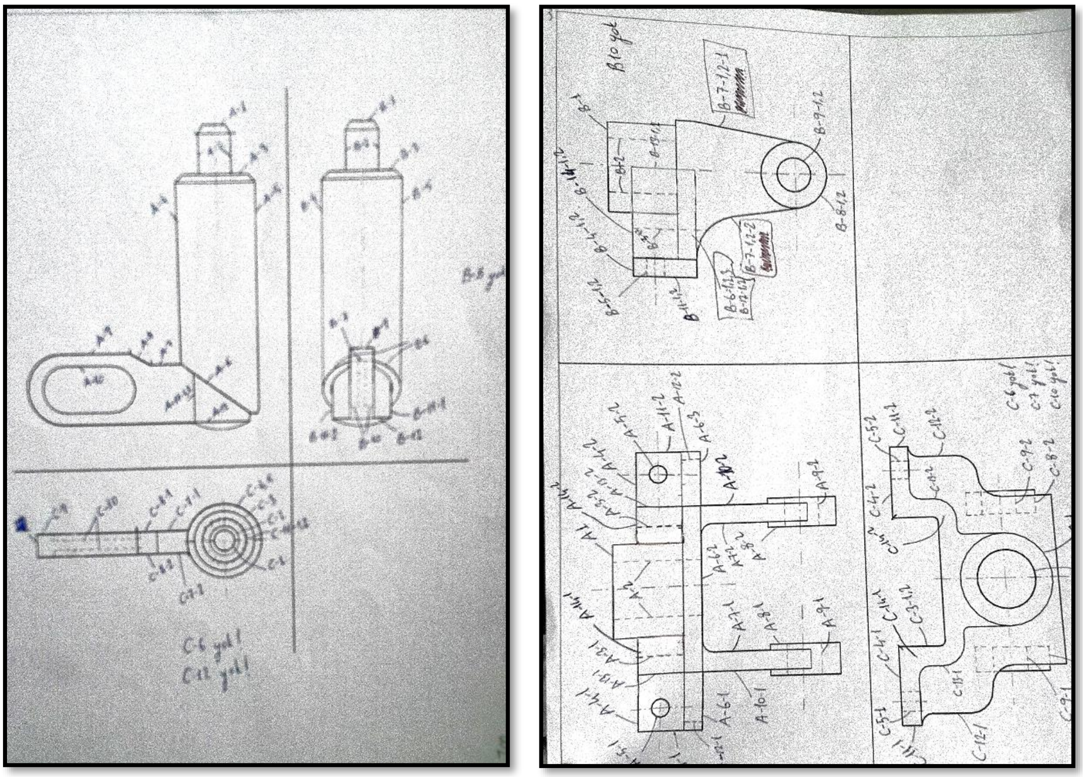


Figure 6. 2D Model's Rubrics of the other Weekly Experiments

Each line to be included in the model answer sheet was evaluated as +1 point as part of *academic achievement criteria*. Each spatial element that students managed to reflect in their drawings were rewarded +1 point as part of *spatial ability criteria*. The points given for three models used in three separate experiments in this study were converted to a scale from 0 to 100, standardizing the all the given grades. Each student can get a maximum of 100 and a minimum of 0 from this test. The Figure 5 and 6 show the rubrics designed for the three experiments and show evaluation criteria. All student papers were assessed according to the same criteria, which ensured the reliability of the assessment tool. The second lecturer also tested the rubric to ensure its validity and reliability.

FINDINGS

In the findings, the authors commented results of data on students' academic performance and spatial ability when using the AR application.

Does an AR application make any difference on students' spatial abilities during technical drawing?

The authors conducted a repeated measures analysis ANOVA. The dependent variable is spatial ability and the independent variables are the experimental and control groups. We have three measurements for each group. The control group was assessed only by paper-based tasks, while the experimental group was assessed by an augmented reality and paper task in the first and second interventions, and by an augmented reality task only in the third intervention. Thus, our research design is a three-factor design.
After determining the dependent (spatial skills for the technical drawing tasks) and independent variables (the control and experimental groups), a repeated-measures analysis (ANOVA) was conducted for the independent variable to examine whether students performed better on spatial skills across the three interventions. While the control group was defined as the "paper-only group", the experimental group was defined as the "AR and paper group" and "AR group only" (see Figure 2).
Participants were assigned to the groups by matching. Observations within each group were conducted independently.
Missing values: at baseline, there were 17 participants in the experimental group and 16 participants in the control group. Three serial measures of three interventions were administered. However, some students did not regularly participate in the interventions. Four students in the experimental group and three students in the control group did not participate in any of the interventions. Therefore, the experiments were conducted with 14 students in each group and a missing values analysis was conducted to replace the mean missing values. There were 5 missing values for the 2nd intervention and 6 missing values for the 3rd intervention (see Table 3).

Table 3. The number of sample size for three experiments

Groups	1st Intervention	2nd Intervention	3rd Intervention
Experimental group	14	12	10
Control group	14	11	12

The repeated measures method ANOVA was used for data analysis because there is a three-times repeated assignment test and a dependent variable (spatial ability). The descriptive table (see Table 4) shows the sample size (n=28), mean and standard deviation of the results.

Table 4. Descriptive statistics of spatial ability scores and technical drawing ability scores at 3 times for each group

Groups		Spatial ability		
		M	SD	N
Experimental	Time 1	38	4.91	14
	Time 2	35	6.72	14
	Time 3	36	7.50	14
Control	Time 1	31	8.58	14
	Time 2	38	8.14	14
	Time 3	34	6.98	14

M: Mean, SD: Standard Deviation, N: Number of students

There are three important assumptions in repeated measures analysis, namely independent observation, normality, and sphericity.
Independent observation: independent observation is one of the most important assumptions in repeated measures analysis ANOVA. The observations within each treatment condition were independent. Therefore, it is assumed that this assumption is met.
Normality: to test the normality assumption, we used the histograms and the skewness and kurtosis values. When we checked the histograms, we found that the normality assumption was not violated. When we checked the values of skewness and kurtosis, the numbers were between [-3, +3] (Tabachnick, & Fidell, 2001; p.72), and we therefore confirmed that the normality assumption was not violated. According to the Kolmogorov-Smirnov normality test, the normality assumption is violated only for the time of the second intervention, p=0.010 0.05; however, the skewness kurtosis values and the histograms show that the normality assumption is met (see Table 5). Consequently, we verified that univariate normality using normality tests and skewness kurtosis values confirmed the normality assumption.

Table 5. Normality values of spatial ability scores

	Kolmogorov-Smirnov(a)			Shapiro-Wilk				
	Statistic	N	Sig.	Statistic	df	Sig.*	Skewness	Kurtosis
time1	.168	28	.043	.911	28	.021	-1.039	1.218
time2	.224	28	.001	.920	28	.035	-.901	.937
time3	.127	28	.200	.959	28	.335	-.055	-.827

*p <0,05

Sphericity Assumption: According to Table 5., Mauchly's test sphericity is not violated p>0,05. In addition, it is assumed that sphericity assumption is not violated according to Greenhouse-Geisser correction, ε=0,949. Therefore, the authors proceeded to conduct repeated measured ANOVA statistical process. Wilk's Lambda value was used to interpret ANOVA results (see Table 6).

Table 6. Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.*	Epsilon(a)		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
time	.946	1.378	2	.502	.949	1.000	.500

*p <0,05

A repeated measures study ANOVA was conducted to examine the effects of the AR intervention on students' spatial skills in three time periods (Time 1, Time 2, Time 3). We chose ANOVA with repeated measures because we had a categorical independent variable with two levels (GROUPS) (the experimental group and the control group) and a categorical independent variable TIME with two levels (Time 1/Time 2/Time 3) and a continuous dependent variable (spatial skills outcomes). There was a significant main effect for both groups with a large effect size $\eta 2=.253$.

When we examined the within-subjects design, we found that there was a significant within-group effect. As summarized in Table 6, $F(2,25)= 4.237$, $p< 0.05$, $\eta 2=.253$, spatial ability scores were significantly different from the three measurements in the previous weeks and increased linearly compared to the previous week(s). The relationship between time and spatial scores is $\eta 2 = 0.253$ has a numerous size effect according to the common guideline proposed by Cohen (1988). According to η2, time can be expected to influence spatial ability scores by 25% (see Table 7).

Table 7. Repeated measures Analyses of Variance for effects of time factor on spatial ability score

Effect		Value	F	df	Error df	Sig.*	η^2
	Wilks' Lambda	.747	4.232[a]	2.000	25.000	.026	.253

* p <0,05

When we checked the between-subjects effects, we found that there were no significant effects between the control group and the experimental group on spatial abilities F (1,26) =.031 p>.05 with very low effect size η2= .031 (see Table 8).

Table 8. *Tests of Between-Subjects Effects of Between-Subject Design*

Source	SS	Df	MS	F	Partial η2
TIME	98880.048	1	98880.048	1020.095	.975
Error	3.048	1	3.048	.031	.001
Total	2520.238	26			

In addition, we found that there was a significant interaction effect within the interaction of time and groups p< .05 F(1,26)=3.116 p=.004 with a very large effect square (.284) following Cohen's reference (see Table 9).

Table 9. Tests of Between-Subjects Effects of Within-Subject Design

Source	SS	Df	Mean Square	F	Sig.	Partial Eta Squared
Time	126.000	1	126.000	3.069	.092	.106
Time * group	423.500	1	423.500	10.315	.004	.284
Error (time)	1067.500	26	41.058			

Does the AR application have an impact on students' academic performance (technical drawing skills) in technical drawing?

The authors conducted a repeated measures analysis ANOVA. The dependent variable is academic achievement, and the independent variables are the experimental and control groups. We have three measurements for each group. The control group was assessed only by paper-based tasks, while the experimental group was assessed by an augmented reality and paper task in the first and second interventions, and by an augmented reality task only in the third intervention. Thus, our research design is a three-factor design.

After determining the dependent (academic achievement) and independent variables (the control and experimental groups), a repeated measures analysis ANOVA of the independent variable was conducted to examine whether students in the three interventions achieved better academic scores on technical drawing skills. While the control group was defined as the "paper only group", the experimental group was defined as the "AR and paper group" and " AR group only". This research problem was conducted in the same research group and with the same research process as the previous problem.
In this problem, repeated measures ANOVA were used for data analysis because there is a three times repeated tasks test and a dependent variable (academic achievement scores). The descriptive table (see Table 10) shows the sample size (n=28), mean, and standard deviation of the results.

Table 10. Descriptive statistics of technical drawing ability scores at 3 times for each group

Groups		Technical drawing ability (Academic achievement)		
		M	SD	N
Experimental	Time 1	25	1.99	14
	Time 2	23	2.83	14
	Time 3	16	2.21	14
Control	Time 1	23	1.99	14
	Time 2	28	2.83	14
	Time 3	23	2.22	14

M: Mean, SD: Standard Deviation, N: Number of students

There are three important assumptions in repeated measures analysis, namely independent observation, normality, and sphericity.
Independent observation: independent observation is one of the most important assumptions in repeated measures analysis ANOVA. The observations within each treatment condition were independent. Therefore, it is assumed that this assumption is met.
Normality: to test the normality assumption, we used the histograms and the skewness and kurtosis values. When we checked the histograms, we found that the normality assumption was not violated. When we checked the values of skewness and kurtosis, the numbers were between [-3, +3] (Tabachnick, & Fidell, 2001; p.72) and therefore we confirmed that the normality assumption was

not violated. According to the Kolmogorov-Smirnov normality test, the normality assumption is violated only for the time of the second intervention, p=0.008 0.05; however, the skewness kurtosis values and the histograms show that the normality assumption is met (see Table 11). Consequently, we verified that univariate normality using normality tests and skewness kurtosis values confirmed the normality assumption.

Table 11. Normality values of technical drawing ability scores

	Kolmogorov-Smirnov(a)			Shapiro-Wilk				
	Statistic	N	Sig.	Statistic	df	Sig.*	Skewness	Kurtosis
time1	.133	28	.200	.931	28	.064	-.711	-.145
time2	.196	28	.008	.954	28	.252	-.443	.275
time3	.117	28	.200	.982	28	.889	-.123	-.468

*p <0,05

Sphericity Assumption: According to Table 12, Mauchly's test for sphericity is not violated p 0.05. Moreover, the sphericity assumption is assumed not to be violated according to the Greenhouse-Geisser correction, ε=0.945. Therefore, the authors performed the statistical procedure of repeated measurement ANOVA. Wilk's Lambda value was used to interpret the ANOVA results (see Table 12).

Table 12. Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.*	Epsilon(a)		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
time	.942	1.486	2	.476	.945	1.000	.500

*p <0,05

A repeated measures study ANOVA was conducted to examine the effect of the AR intervention on student outcomes in technical drawing (academic performance) in three time periods (Time 1, Time 2, Time 3). We chose ANOVA with repeated measures because we have a categorical independent variable with two levels as GROUPS (the experimental group and the control group) and a categorical independent variable TIME with two levels (Time 1/Time 2/Time 3) and a continuous dependent variable as technical drawing skills outcomes. There was a significant main effect for both groups with a large effect size η2=.305.

When we examined the within-subjects design, we found that there was a significant within-group effect. As summarized in Table 13, F(2,25)= 5.493, p<0.05, η2=.305, the technical drawing skills scores were significantly different from the three scores measured in the previous weeks, and they increased linearly compared to the previous weeks (see Figure 1). The relationship between time and technical drawing skill scores has a very large size effect with η2 = 0.305 according to the general guideline proposed by Cohen (1988). According to η2, time can be considered to have an influence of 30% on the technical drawing skills scores (see Table 13).

Table 13. Repeated measures Analyses of Variance for effects of time factor on technical drawing ability score

Effect		Value	F	df	Error df	Sig.*	η^2
	Wilks' Lambda	.695	5.493[b]	2.000	25.000	.011	.305

* p <0,05

When we examined the between-subjects effects, we found that there were no significant effects between the control group and the experimental group in technical drawing skills (academic performance) F (1,26) =1.414 p<.05 with a very small effect size η2= .052 (see Table 14). When the mean scores in the table are examined, the measurements between the experimental and control groups are not parallel to each other. In other words, the groups changed in different ways over time. In the weekly measurements, the experimental group was higher than the control group on the first application and their average decreased on subsequent applications. The control group showed an increase in technical success at the second and third applications compared to the experimental group.

Table 14. Tests of Between-Subjects Effects of Between-Subject Design

Source	SS	Df	MS	F	Partial η2
Time	44666.298	1	44666.298	291.175	.918
Group	216.964	1	216.964	1.414	.052
Error	3988.405	26	153.400		

In addition, we found that there was a significant interaction effect within time and group interaction p<.05 F(1,26)=7.483 p=.011 with a very large effect eta squared (.223) by Cohen's reference (see Table 15). Furthermore, when controlling for the time- group interaction, there was a significant difference in the time-group interaction (time * groups) (p .05 F (1,26) = 7.708 p = .010).

Table 15. Tests of Between-Subjects Effects of Within-Subject Design

Source	SS	Df	Mean Square	F	Sig.	Partial Eta Squared
Time	320.643	1	320.643	7.483	.011	.223
Time * group	330.286	1	330.286	7.708	.010	.229
Error (time)	1114.071	26	42.849			

DISCUSSION

AR applications are defined in the literature as support materials in educational settings (Fonseca et al., 2014; Akçayır & Akçayır, 2017). Prieto and Velasco (2010) conducted a study to investigate how to improve spatial skills in technical drawing course and showed that students performed better in a drawing course supported with visual and virtual materials instead of printed materials. Some studies have shown that AR contributes to deeper learning by providing a view of a particular object or system from different angles (Hsiao & Rashvand 2011; Kerawalla, Luckin, Seljeflot, & Woolard 2006; Deshpande & Kim, 2018; Hoe et al., 2019).
When repeated measures analysis of variance was performed, a statistically significant difference was found when the total weekly measurements of each group (the experimental and control groups) were compared. In a study of 224 undergraduates, researchers examined the effects of AR on engineering students' spatial skills. They found that the spatial ability scores of the experimental group that studied with the AR application were higher than those of the control group (Martin-Gutierrez et al., 2012; Gómez-Tone et al., 2020). In another study, first-year mechanical engineering students at a Spanish university worked regularly on some 3D models designed for a AR application. The results showed that the spatial skills of the students in the experimental group who used the AR application improved significantly compared to those in the control group (Martin-Gutierrez et al., 2010). In fact, not only AR, but also some SA tests were found to have a positive effect on performance and spatial skills when used in engineering graphics classes (Leopold, Gorska, & Sorby, 2001; S. A. Sorby, 2009; Deshpande & Kim, 2018; Sheharyar et al, 2020; Gómez-Tone et al, 2020).

According to the repeated measures analyses, there was no significant difference between the test and control groups in terms of spatial skills performance scores: F (1,26) = 031 p .05. The mean scores, curves of the experimental, and control groups obtained from the weekly measurements also support this conclusion. While the experimental group scored higher in the first week, the control group scored higher in the second and third weeks. Yuen and Chen (2001) investigated the effects of computer-assisted design on spatial skills in their experimental study and found no difference between the experimental and control groups. Deshpande & Kim (2018) conducted an experimental study to assess the effects of AR on spatial skills in assembling objects. The result of their study was that the application effectively improved spatial skills. Gómez-Tone et al. (2020) conducted an empirical investigation using AR in relation to spatial skills. The results were effective as both experimental groups were able to significantly improve their spatial abilities.

There are two criteria for evaluating interaction within the group. The first criterion is "time" and is used to ask whether there is a significant difference between the three-week measurements of the experimental and control groups. The other criterion is time*group interaction. This measurement is to show whether being in the experimental or control group has a significant effect on spatial ability and whether there is an interaction between time and groups. When the results of the analysis and the value of the squared effect size between groups ($\eta2 = .284$) are taken into account, it can be seen that the within-group variable accounts for 28% of the variance in the dependent variable, indicating a significant difference. That is, the within-group interactions (time * group) showed a significant difference, while there was no significant difference between the experimental or control groups.
The analyses of the between-group measurements showed that there was no significant difference, F (1,26) = 1.414 p .05, between the technical performance scores of the experimental and control groups. In the literature on this topic, some experimental studies have been conducted in education and it was found that AR applications have no significant effect on achievement in these studies (Cai et al., 2013; İbili, 2013).

When we control for interaction effects within groups, we encounter two measures. The first variable is "time"; it asks whether there is a significant difference between the three-week applications of the experimental and control groups. The second, "time * group," measures the joint effect of the interaction between groups and measurements. The significance of this measurement is whether being in the experimental or control group has a significant effect on technical performance scores. As a result of the evaluation, no significant difference was found between the experimental group and the control group, but according to the "time * group" results of the interaction within the group changes in different directions. Moreover, these results showed that the groups were not parallel to each other. There was a significant difference in the within-group interactions. Although there is no direct study in the literature on the success of technical drawing AR applications, some studies have been conducted in relation to the development of materials to support technical drawing that have been shown to be effective. Cardoso et al (2019) developed an approach to improve technical drawing using the tools from AR. They found that AR technology improves and facilitates technical drawing in engineering.

The integration of technology into the classroom can be considered the main reason for the observed improvement in spatial skills of the group using the AR application. New technologies, when used in educational environments, attract students' attention and increase their interest and motivation (Ong, Shan and Nee, 2009; Kreijns et al., 2013). However, the novelty effect should also be considered here. The application created a novelty effect in the students, which caused the average scores of the experimental group to decrease within weeks.

Student opinions were obtained and observations were made during measurements taken at the end of each week of the three-week research period. It was found that students found the application useful, beneficial, enjoyable, interactive, and effective. Similar conclusions were reported in the studies where AR was found to be useful and convenient (Chang et al., 2011; Wojciechowski and Cellary 2013; Yusoff et al., 2011; Sheharyar et al., 2020). Another reason for the positive feedback from the control group is that these students were working with a new technology. This fact has been reported in other studies in the literature. AR technology creates a novelty effect when it is used in education (Di Serio et al., 2012). The students who participated in this study indicated that the application could work better with few improvements. This result is also supported by the conclusions from other studies in the literature (Shen, Ong and Nee, 2010).

Students' opinions indicated that the AR application was effective in the technical drawing course. The students who found the application effective and useful reported that the AR application helped them easily visualize the model they were trying to draw. Moreover, interactive animations and virtual bodies are useful tools for spatial skills in engineering (Cohen & Hegarty, 2014; Sharma, Murugadoss & Rambabu, 2020). These findings are similar to those of Bujak et al.'s (2013) study, which suggests that the AR application creates a sense of reality and helps students visualize the model they are drawing. In this way, students can have more fun in class and become more motivated (Wojciechowski and Cellary, 2013; Carrera & Asensio, 2017). The literature reports that the applications of AR facilitate learning by correcting misconceptions and transforming abstract ideas into a tangible reality (Wu et al., 2013). Augmented Reality creates a composite view by overlaying a computer-generated image with the user's view of the real world; therefore, it is an effective means of creating a sense of reality (Milgram and Kishino, 1994; Azuma, 1999; Billinghurst, Clark & Lee, 2015; Wu et al., 2013). The students who participated in this study reported that using paper and augmented reality simultaneously facilitated drawing. Some studies in the literature also reported that students developed greater interest in the course material due to the convenience provided by AR technologies (Kaufmann and Duenser, 2007; Di Serio et al., 2012). Technical support may be another element that positively influenced students' attitudes toward the AR application. Before starting the implementation, students received some introductory information about the system. Literature reported that users need technical support when using AR application (Dunleavy et al., 2009). One of the technical problems encountered by the students in this study was calibration. They reported that they had some difficulties holding the QR code to the screen to see the 3D model and that there were some symmetrical errors with the model displayed on the screen. It has been reported in the literature that the cameras of the hardware devices may not recognize the images defined as markers under adverse environmental conditions (Kato & Billinghurst, 1999; Hirzer, 2008; Arth & Schmalstieg, 2011; Noghabaei et al., 2020).

The students in the experimental group found it easier to work with the AR application and the paper as introduced in the first two weeks of the study, and they indicated that they wanted to continue their studies with both. However, most students chose to work with either the AR application or paper only. Only one student indicated that the AutoCAD application was superior to both the AR application and paper. The students in the experimental group also indicated that they wanted to use this application as a personal learning tool. Similarly, it has been reported in the literature that users are attracted to AR applications because of the utility and convenience they provide (Chang Chen, Huang, & Huang, 2011; Wojciechowski & Cellary 2013; İbili, 2013).

CONCLUSION & SUGGESTIONS

The results of this study have shown that the applications of AR can make an important contribution to education, especially engineering education. However, the quantitative results have also revealed some shortcomings. The following are some suggestions on the impact of AR on students' spatial skills in engineering education today and in the future. AR applications only provide a mobile output, as we have seen in the development of the AR application used in this study. Platform independence should be considered in the development of future applications. We suggest AR to investigate students' attitude and motivation. It would be useful to conduct similar research as part of future studies. In the pilot implementation, students had some problems with marker positioning and calibration, which negatively affected the efficiency of the experiment and students' motivation. These errors should be eliminated in future studies. AR is a popular technology in education. Therefore, it is useful to conduct pre-tests to assess users' familiarity with the AR applications to be used in the experiment. The students who participated in this study indicated that the application should be more interactive. The content of the application could be enriched with certain interface elements and tools in future studies. Finally, researchers should monitor student attendance at weekly walkthroughs to derive accurate results from their studies.

Implications and Suggestions of Practical Implementations / Instructions for Teachers:

- Those who want to do research in engineering education in AR applications should first do a good field study. They can opt for the best software and kits that can be used in field survey engineering.
- Before developing an AR application, expert opinions should be sought and the educational aspects should be considered. Applications that are supported by field experts are error free.
- In this study, dynamic AR applications were used, but the development of more active and user-controlled applications could lead to different results. It is certain that researchers in this field will contribute by doing more interactive work with the new generation of AR software kits and AR glasses.

Ethics and Consent: Ethics committee approval is not required since the data is collected before 2020.

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