An Exploration of Augmented Reality in an Introductory Engineering Graphics Course

Timothy Thornton & Matthew Lammi

Abstract

The purpose of the study was to explore the effects of augmented reality (AR) in an introductory engineering graphics course. The study specifically examined the potential for AR to affect the spatial visualization ability of students and influence student motivation. This study included 50 students from an introductory engineering graphics course at a large southeastern US public university. The AR intervention consisted of six weekly sessions in which students were required to complete an assignment with the assistance of AR. Two quantitative measurements were employed to measure the results of the implementation. The Purdue Spatial Visualization Test: Rotations (PSVT-R) was used to measure spatial visualization ability, and the Motivated Strategies for Learning Questionnaire (MSLQ) was used to measure student motivation. Both instruments used a pre- and post-test format and were analyzed with paired *t*-tests. The results of the PSVT-R ($p < .01$) showed a significant difference between the pre- and post-test scores; however, this could not be solely attributed to the implementation of AR. The results of the overall MSLQ ($p = 0.57$) showed no significant difference between pre- and post-test scores.

Keywords: spatial visualization, augmented reality, motivation

Introduction

The purpose of this study was to investigate the effect of an augmented reality (AR) intervention on student motivation and spatial visualization ability in an introductory engineering graphics course. The impact of AR was analyzed from two unique perspectives: the role of AR as a visual tool to improve spatial visualization skills and the potential of AR to positively influence a student's motivation to learn. The spatial visualization skills and motivation were measured by the Purdue Spatial Visualization Test: Rotations (PSVT-R) and the Motivated Strategies for Learning Questionnaire (MSLQ), respectively.

In engineering graphics, visual thinking serves as a means of communication and a tool for reasoning, leading to visual thinking throughout the engineering curriculum. Through visual thinking, students learn to visually comprehend concepts and develop their spatial ability—"the ability to generate,

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retain, and manipulate abstract visual images" (Lohman, 1979, pp. 126–127). McGee (1979) further elucidates spatial visualization skills as "the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object" (p. 893). Because it has multiple implications, spatial ability continues to be actively researched (Sorby et al., 2014). Several studies have highlighted spatial ability as a component for success in engineering courses (Burton & Dowling, 2009; McGee, 1979; Sorby, 2009). Students who do not perform well in these introductory engineering courses are more likely to fail, change majors, or transfer from the program.

It has been suggested that greater emphasis should be placed on visualization skills in education (Alias et al., 2002). The development of spatial visualization skills in an introductory engineering graphics course is typically the student's first exposure to engineering principles at the collegiate level. In general, introductory engineering courses consist primarily of first-year engineering students (Crown, 2001). In these courses, spatial visualization skills can be developed through sketching, design, and computer-based modeling. Nearly all the topics encountered in an introductory engineering graphics course address three-dimensional (3D) objects or concepts that are often difficult to visualize. The ability to visualize is a powerful tool because it allows one to manipulate a model, mentally understand a model, and develop models not yet created (Bertoline et al., 2011).

Spatial visualization skills can improve over time. Potter et al. (2006) concluded that a student's 3D spatial perception is trainable and will develop through their first year at a university. Visualization skills can also be improved through teaching and learning (Alias et al., 2002; Güven & Kosa, 2008). These studies indicated that spatial visualization skills can improve regardless of AR implementation. Visualization skills are required by students in the creation of 3D models. Modeling allows the user to represent abstract ideas, words, and forms through the orderly use of simplified text and images (Bertoline et al., 2011). This begins with graphics communications—the exchange of information in a visual format that allows for the effective communication of ideas—which is a central theme within introductory engineering graphics courses (Prust, 2003). Students begin the process by interpreting engineering drawings, transition into sketching, and, finally, evolve into 3D modeling using CAD software. To accomplish these tasks, students must be able to take a 2D drawing and mentally visualize it as a 3D object.

Augmented Reality

Azuma (1997) defined AR as allowing "the user to see the real world, with virtual objects superimposed upon or composited with the real world" (p. 356). AR operates by augmenting the landscape with digital information, allowing the user to gain additional information about their surroundings or through the enhancement of an object (Billinghurst et al., 2001). AR enhances an individual's physical environment through a collaboration of the virtual and real environments (Azuma, 1997), allowing the viewer to superimpose a 3D virtual object onto a real-world environment (Thornton et al., 2012). Additionally, AR allows users to turn models into 3D objects that become interactive, creating a more authentic learning experience with the real-world environment (Goldiez et al., 2004).

Multiple studies have highlighted the use of AR as a visualization tool to enhance the learning experience of students (Allen et al., 2011; Bell et al., 2018; Dünser et al., 2012; Schiavone, 2020). Allen et al. (2011) noted that AR helped subjects visualize the intention of the design, and Dünser et al. (2012) suggested that AR has the potential to assist in the learning of 3D concepts. Studies by Bell et al. (2018) and Schiavone (2020) highlighted the ability of AR to enhance the spatial visualization skills and reasoning of low-performing students.

Numerous studies have been conducted on the use of AR in engineering graphics (Dorribo-Camba & Contero, 2013; Martín-Gutiérrez et al., 2015; Huffman & Miller, 2012). Huffman and Miller (2012) compared the use of AR to traditional physical models, finding no significant difference between the use of AR blocks and physical blocks. A study conducted by Martín-Gutiérrez et al. (2015) found that AR improved academic performance and student motivation. Dorribo-Camba and Contero (2013) used an AR system in combination with other materials to improve the spatial visualization skills of engineering students.

The value of AR may be linked to its use as a motivational tool to enhance the learning process. In education, the use of AR allows students to take an active role in their own learning. Accordingly, students are engrossed and may be motivated to learn new skills to solve problems (Norman & Spohrer, 1996). Studies have indicated that AR can serve as a motivational factor, increasing interest and curiosity and leading to improved academic performance (Campos et al., 2011; Fonseca et al., 2014; Yechkalo et al., 2019). Numerous studies have highlighted AR's ability to provide an immersive learning environment (Lee et al., 2010; Wu et al., 2013). Additional studies indicated that the ability to interact with AR was motivational (Mladenović et al., 2015; Redondo et al., 2013) and provided a learner-centered approach to instruction (Kamarainen et al., 2013).

Academics and researchers have identified the need for strong spatial visualization skills in engineering graphics as well as the potential for AR to enhance spatial visualization skills. There is a gap in the literature that fails to fully explain how best to utilize AR in an introductory engineering graphics course. This study addressed that gap by examining how an AR intervention could be used to enhance students' spatial visualization skills and positively affect their motivation to learn. The purpose of this study was to further the understanding of how AR could impact students in an introductory engineering graphics course in terms of their spatial visualization skills and motivation. The following research questions served to focus the study.

1. To what extent does an augmented reality intervention enhance the motivation of students to learn an introductory engineering graphics course?

2. To what extent does an augmented reality intervention enhance the spatial visualization skills of students in an introductory engineering graphics course?

Methodology

A pretest–intervention–posttest methodology was employed to determine the effects of AR on participants' spatial visualization and motivation. Numerous researchers have used a pre-and post-test format to measure changes in spatial ability (e.g., Alias et al., 2002; Blasko et al., 2009; Sorby & Veurink, 2010).

Study Context

The study was conducted in two sections of an introductory engineering graphics communications course (GC 120) at a large public university in the southeastern US. Both sections were taught by the same instructor, followed the same syllabus, and had identical requirements. The instructor had taught the GC 120 course for 13 years and had developed a uniform approach to all of his sections, including identical assignments, projects, tests, a book, CAD software, tutorials, and a Moodle website.

Permission to conduct the study was granted by the university's Institutional Review Board. Participation in the study was voluntary and written informed consent was obtained from each participant. Students were aware that they could withdraw from the study at any time without penalty. To increase student participation, compensation was offered in the form of extra credit; however, there was an alternative assignment for those who chose not to take part in the study. Both of the GC 120 sections were considered hybrids and included both a face-to-face and online component. The courses met face-to-face on Wednesdays, and optional help sessions were held on Mondays. All course content was delivered on Wednesdays. The optional help sessions, open to all students, offered students the opportunity to get assistance with questions or assignments.

Participants

A total of 120 students were enrolled in the two sections of GC 120, a requirement for all engineering majors. Of the 120 students enrolled, 50 volunteered to participate in the study. Participants were predominately male

(70%) engineering majors (92%). The academic levels of participants were 26% freshman, 50% sophomore, 18% junior, and 6% senior. The distribution of academic levels indicated that this was the first engineering graphics course for most students.

Treatment and Assignments

The AR software selected for this study was Augmented® and was developed by Augmentedev®. The software was selected because of its compatibility with SolidWorks and ability to be displayed on an iPad. The AR models were created in SolidWorks, saved as STL files, and then uploaded to an iPad.

The AR treatment was implemented during help sessions on Mondays. Only the participants involved in the study attended the six sessions and completed all six assignments (see Table 1). All the assignments aligned with the course content and increased in difficulty. All assignments originated from the *Fundamentals of Graphics Communication* (Bertoline et al., 2011). A make-up

Table 1
Augmented Reality Assignment Schedule

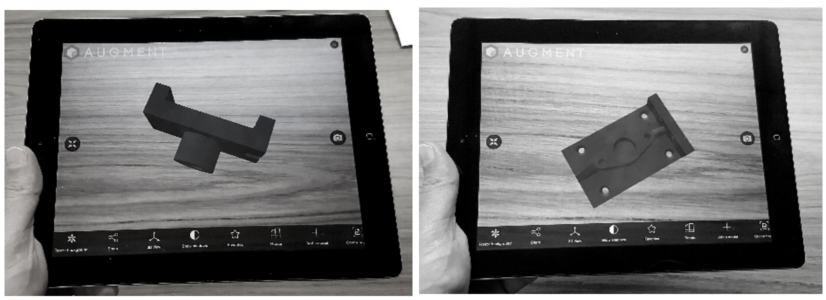
Number	Week	Assignment
1	4	Develop geometric relations (Problem 2, p. 337)
2	5	Fillet, concentric relations or tangential relations, the fillet command, and symmetry, respectively (Fig. 5.142, p. 307 or Fig. 5.130 p.305)
3	6	Illustrate design intent and corresponding extrusion heights (Model 4, p. 484)
4	7	Refine geometric relations (Fig. 5.148, p. 308)
5	9	Concentric relations, angled cuts, and use multiple cut-extrude commands, and radially aligned features (Fig, 5.146, p. 308)
6	10	Concentric and tangential features (Fig. 5.147, p. 308)
Make-Up	11	Non-tangent lines, rounded corners, and fillets (Fig. 5.135, p. 306)

Note. All problems adapted from Bertoline, G. R., Wiebe, E. N., Hartman, N. W., & Ross, W. A. (2011). *Fundamentals of Graphics Communication* (6th ed.). McGraw–Hill.

session was provided for students who missed one of the six sessions. The number of participants who attended each session ranged from 40 to 50.

Each of the six sessions lasted 90 minutes, a total of 9 treatment hours. At the start of each session, students received an iPad with a preloaded AR model and were instructed on how to use the AR system by the researcher (see Figure 1). During this time, the researcher modeled the proper technique and methods and provided a step-by-step demonstration.

Figure 1.
Augmented Model on iPad

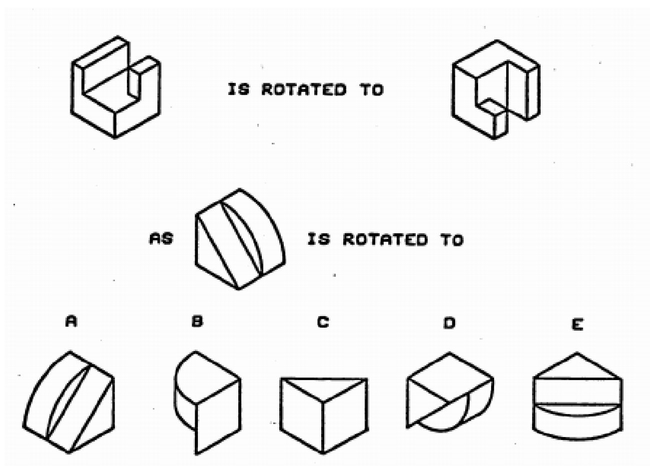


During each session, students analyzed and manipulated the model prior to starting the assignment and could refer to the AR model throughout the session. Then, students created a model in SolidWorks with the assistance of the AR software and the 2D sketch in the book. The AR software placed the virtual model in a real-world environment, allowing students to manipulate and interact with the 3D model, whereas the 2D sketch provided students with the dimensions of the model. Upon completion of the assignment, the students emailed the modeled part file to the researcher.

Instruments

The decision to use multiple assessment instruments in this study was supported by the research findings of Clark and Ernst (2012). Clark and Ernst (2012) recommended that specific assessment instruments were needed to address the motivation to learn, learning strategies and preferences, and spatial visualization ability of students in introductory engineering design graphics courses. The PSVT was selected for this study because of its ability to measure spatial visualization skills (Branoff, 2009). The PSVT consists of three sections: developments, rotations, and views. The only section included in this study is rotations (see Figure 2). According to Ault and John (2010), “most graphics researchers use only the object rotations portion” of the PSVT (p. 13). The PSVT-R is a spatial ability test that provides students with an object and then rotates this object and asks the student to select the correct rotation (Guay, 1980). The instrument is designed to evaluate the student's ability to visually comprehend the rotation of the object. The instrument includes 30 multiple-choice questions consisting of 13 symmetrical and 17 nonsymmetrical figures of 3D objects, all of which are displayed in a 2D isometric format.

Figure 2.
A Sample PSVT-R Question. From Spatial Ability Measurement: A Critique and an Alternative (p. 8)*, by R. B. Guay. Copyright 1980 by R. B. Guay*



The first research question proposed within this study was whether AR affected students' motivation to learn in an engineering graphics course. The instrument that was administered to answer this question was the MSLQ. The MSLQ is a self-report instrument chosen because of its ability to measure student motivation in a college classroom (Pintrich et al., 1993). The two sections contained within the instrument are motivation orientation and learning strategies. For the purpose of this study, only the motivation orientation component was utilized. There were five subscales within the motivation orientation component examined: intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, and self-efficacy for learning and performance. A sixth component, affection, was omitted because it assesses test anxiety, which was not addressed in this study. Additionally, the entire learning strategies section was also excluded because it was not relevant to the research questions.

Data Collection Methods

All participants completed a pre- and post-test of both the MSLQ and PSVT-R. The MSLQ and PSVT-R were initially scored by the researcher and then fact-checked for consistency by a colleague in the program. The pretest for the PSVT-R was given 2 weeks prior to the start of the treatment, and the pretest MSLQ was given during the first day of the treatment. The MSLQ posttest was administered during the last treatment session, and the PSVT-R posttest was administered 3 weeks later.

The results of the pre- and post-test PSVT-R and MSLQ were analyzed using a paired *t*-test. A *t*-test was selected to compare the means of two sets of data and determine if there was a significant difference. Researchers have used paired *t*-tests to compare spatial gains (e.g., Connolly, 2009; Gorska et al., 1998; Güven & Kosa, 2008). Additionally, a paired *t*-test was used by Milner et al. (2011) to compare mean scores on the MSLQ.

Results and Analyses

The purpose of this study was to further the understanding of how AR could impact an introductory engineering graphics course. Data was collected from a pre- and post-test PSVT-R and a pre- and post-test MSLQ. The results of the PSVT-R were analyzed to answer Research Question 1, and the results of the MSLQ were analyzed to answer Research Question 2.

Spatial Visualization

Initially, descriptive statistics were analyzed and compared (see Table 2). Students possessed high spatial skills prior to beginning the study with a pretest mean score of 24.6 (82%). Additionally, 90% of the students scored higher than 60%. According to Sorby and Veurink (2010), a score of more than 60% was considered passing, and the average score was 75%. The mean score of the posttest was 25.9, with 98% of the students scoring at least 60%. The results of the paired *t*-test showed a significant statistical (t = -10.267, p = .001) difference between the pretest (M = 24.6, SD = 4.13) and posttest PSVT-R scores (M = 25.9, SD = 4.09; see Table 3).

Table 2
Results of the PSVT-R (N = 50)

	Min	Max	*M*	*SD*
Pretest	13	30(4)	24.6	4.13
Posttest	12	30(7)	25.9	4.09

Table 3
Paired Samples t-Test for PSVT-R

	M	*SD*	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pre–post PSVT-R	1.280	.8826	.125	1.53	1.036	-10.267	49	.001

Student Motivation

The differences between pre- and post-test scores were analyzed for five MSLQ subscales and an overall MSLQ (see Table 4). Of the five subscales, only the intrinsic goal orientation subscale showed a statistical difference (see Table 5). Subscales of extrinsic goal orientation, task value component, control of learning beliefs, and self-efficacy showed no statistical difference. In addition, there was no statistical difference between pre- and post-test scores on the overall MSLQ.

Table 4
Comparison of Scores for MSLQ Subscales by Test

		Pretest		Posttest	
MSLQ Subscale	*N*	*M*	*SD*	*M*	*SD*
Value component: Intrinsic goal orientation (1)	50	5.08	.43	5.31	.41
Value component: Extrinsic goal orientation (2)	50	5.59	.28	5.53	.43
Task value component (3)	50	5.57	.21	5.54	.28
Control of learning beliefs (4)	50	5.81	.43	5.76	.36
Self-efficacy – Learning Performance (5)	50	5.59	.32	5.57	.26
Overall MSLQ summary	1297	5.53	1.19	5.57	1.16

Discussion and Implications

The intent of the study was to determine the influence of an AR intervention upon undergraduate students' spatial visualization abilities and motivation. Due to the exploratory nature of the study, no control or comparison groups were used. Additionally, there were no restrictions on the amount of time students could spend on a task. Both of these are limitations that could influence the findings.

Table 5
Paired Samples t-Test for the Motivation Orientation Section and Subsequent Subscales of the MSLQ

	Mean Difference	*SD*	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	*t*	*df*	Sig. (2-tailed)
Intrinsic goal orientation	.22	1.26	.09	.4	.05	2.48	198	.01
Extrinsic goal orientation	-.06	1.32	.09	-.15	.22	-.38	199	.71
Task value	-.03	1.23	.07	-.13	.15	-.14	298	.89
Control of learning beliefs	-.05	1.22	.09	-.16	.22	-.52	197	.60
Self-efficacy for learning performance	-.02	1.22	.06	-.18	.06	-.99	398	.32
Overall pre–post	.04	1.25	.03	-.11	.03	1.1	1299	.27

The results of the PSVT-R paired *t*-test showed a statistically significant difference between pre- and post-test scores, indicating that the spatial visualization skills of the students improved. The results of the MSLQ paired *t*-test indicated that AR had a positive influence on the intrinsic motivation of the students in the study. The subscale of intrinsic goal orientation addresses to what degree the student perceived participation to be associated with tasks for reasons such as challenge, curiosity, or mastery (Pintrich et al., 1991). No statistically significant difference was found between the pre- and post-test scores of the other four subscales or overall MSLQ.

There are potential explanations for the gains in the posttest PSVT-R scores. For one, the increase in posttest scores could be attributed to AR's ability to reduce the learning curve and reduce mistakes that students make when applying new concepts (Ayasoufi et al., 2019; Larsen et al., 2013), which could be achieved through the ability to interact and manipulate structures or analyze models from multiple angles (Núñez et al., 2008). This finding aligns with the results of several other studies that highlighted the ability of AR to impact spatial visualization skills (e.g., Allen et al., 2011; Dorribo-Camba & Contero, 2013; Martín-Gutiérrez et al., 2015; Medicherla et al., 2010; Sheharyar et al., 2020). There could be other reasons for the increase in posttest scores; for instance, the improvement in students' PSVT-R scores could be a result of taking the engineering graphics course. Studies conducted by Alias et al. (2002), Connolly (2009), and Sorby and Baartmans (1996) found that students' spatial skills were improved through curriculum content. Furthermore, this study required students to spend an additional 9 hours modeling in SolidWorks. The additional time spent modeling in SolidWorks may have allowed them to further develop their visualization skills.

The MSLQ pretest and posttest scores were analyzed for five subscales and overall scores. A significant statistical difference was evident only in intrinsic goal orientation. The results were encouraging because Eccles et al. (1998) and Wigfield et al. (2006) found that interests, intrinsic motivation, and intrinsic value were all predictors of increased academic engagement and learning. Understanding intrinsic motivation in engineering graphics is important because of student retention issues. Student retention remains a pertinent issue with engineering majors, especially during their freshman year (Sheppard & Jennison, 1997). A student who struggles during the beginning of their academic career may become discouraged and withdraw from the engineering program (Sorby, 2005).

Based upon these findings, we assert that there are further opportunities to investigate the use of AR within engineering graphics or any course that emphasizes visual comprehension. Research could be conducted on the use of AR as a visual tool to enhance lectures and reduce instructional time. During the lecture, the instructor could display the AR model and use it as a learning tool for visual concepts. Chen et al. (2011) noted that AR was able to reduce the time instructors spent in a classroom and that AR-based learning provides flexibility, self-paced instruction, and immediate feedback. Both Fonseca et al. (2014) and Parmar et al. (2015) investigated new AR methods that complement and enhance the teaching process.

The students who participated in this study possessed high visualization abilities. Future research can be conducted on the effect that AR has on students with low and high visualization abilities. Additionally, research could be conducted on the use of AR to improve the skills of students with low spatial visualization scores. Medicherla et al. (2010), Schiavone (2020), and Tatzgern et al. (2015) noted that AR had a positive impact on the students' learning experience, particularly among students with lower spatial visualization ability. To better understand the potential of AR, specific content needs to be developed. The design of specific content for AR could lead to a clearer understanding of what makes the technology engaging and attractive and allow instructors to fully utilize the benefits of AR (Martín-Gutiérrez et al., 2010; Radu, 2014). Exploratory research is needed to analyze the potential benefits of using mobile devices and apps to deliver AR. Chang et al. (2014) believe that mobile AR promotes engagement and holds the potential to motivate students to further examine the content. This stance was corroborated by Bairaktarova et al. (2019), who used an AR mobile app to enhance the spatial reasoning skills of low-performing students. Finally, additional research should be conducted on the use of AR as a tool to promote collaboration. Studies by Kamarainen et al. (2013) and Radu (2014) note that the flexibility afforded by AR creates a collaborative working environment that promotes student interaction. Researchers are continuously finding increased educational applications for AR (Mladenović et al., 2015), as evident by the growing wealth of research being conducted (Bacca et al., 2014). This study adds to that growing knowledge and presents an option for the utilization of AR in an engineering graphics classroom.

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About the Authors

Timothy Thornton (Timothy.Thornton@athens.edu) is Assistant Professor in the Career and Technical Education Program at Athens State University.

Matthew Lammi (Mdlammi@yahoo.com) is Project Manager at Black & Veatch.