A Study of an Augmented Reality App for the Development of Spatial Reasoning Ability

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Abstract

This study builds on prior work testing the use of augmented reality (AR) on smartphones for developing spatial reasoning in the context of a spatial reasoning skills course. Various strategies were employed to increase engagement, including anonymous screen name rankings, comparison with personal best scores, and badges for additional progress and practice within the app.

The participants for this study included forty-five (n=45) first-year pre-engineering students at a major Midwestern university who performed poorly on the PSVT:R spatial abilities test. These students were all enrolled in a class designed to improve their spatial abilities. The subjects were split into control and experimental groups. Members of the experimental group were compared with the students who took the same course minus the augmented reality app. Both sets of students experienced traditional means for teaching spatial reasoning.

Multiple measures were compared for these groups of students. In particular, we compared:

- Performance on the PSVT:R spatial abilities test (pre and post)
- Student attitudes, including their confidence and enjoyment of spatial abilities tasks

The results of this study revealed no significant difference between the experimental and control groups in terms of PSVT:R growth. It did show significant benefit for females in the experimental condition as compared to females in the control group.

Introduction

Spatial reasoning is an important predictor of student success in STEM fields [1], [2]. Sorby reports that spatial cognition has been a focus of research for nearly a century. One important part of spatial cognition is "spatial visualization, which is defined as the process of 'apprehending, encoding, and mentally manipulating three dimensional spatial forms'" [3].

Given this importance of spatial visualization, an important question is if and how students' spatial visualization skills can be developed. Sorby studied the effect of students taking a 1-credit spatial skills course, and found multiple benefits: improved performance in introductory engineering courses, improved STEM GPAs, and greater retention for women in engineering [1].

Given that a spatial skills course can help, an important next question is what specific strategies in such a course would be most valuable. One way to classify these strategies is through the representation of three-dimensional objects that is used in the educational opportunities. Sorby [1] classified these representations as tangible and virtual, and we would also add abstract. Abstract approaches rely on two-dimensional drawings, such as those used in a textbook by Sorby [5]. Tangible objects include the use of physical blocks and related objects [6]. Purely virtual representations include computer-based animations, simulations, and virtual reality [7], [8], [9], [10], [11], [12]. An important variation on abstract representations is the use of sketching [13], along with the use of technology to provide immediate feedback on hand sketching [14]. Technology also offers the possibility of a blend of tangible and virtual representations. Ha and

Fang [4] describe "Virtual and physical manipulatives" in which physical objects can have a secondary connected representation in a digital space.

Augmented reality offers the possibility of the illusion of physical representation in a digital space [12]. Bell, et al. [15] argue that augmented reality makes possible "a closer integration between the 3-D object and the abstractions that are a part of engineering manipulation." Doing so offered "the ability to create interactions that would be harder to create with physical objects." It also creates greater ability to control student experiences and to gather data on their interactions.

Prior studies of augmented reality have been mixed, with some finding significant benefit, e.g., [16] and [17], with students who used augmented reality growing significantly more in their mental rotation scores as compared to students who used "the conventional method" (presumably using abstract representations, such as paper and pencil based 2-dimensional drawings). Bell, et al. [18] found significant benefit for those with poor incoming spatial abilities and that augmented reality narrowed the gender gap that had been found in a conventional classroom approach.

One of the questions raised in this latter study is if greater time invested in the augmented reality app would lead to greater learning gains. In this study, we endeavored to build on the work of Bell, et al., by structuring the app and its use to see what effects it would have on student attitudes and student learning.

Our Approach

For this study, we used a handheld augmented reality app that was designed to work on students' smartphones or tablet computers. Students were given a printed target (marker) that served as the anchor for the digital objects displayed as augmented reality objects (see Figure 1). Students could move the printed target, or they could move their phones (including standing up and walking around) in order to see the digital objects from various angles.
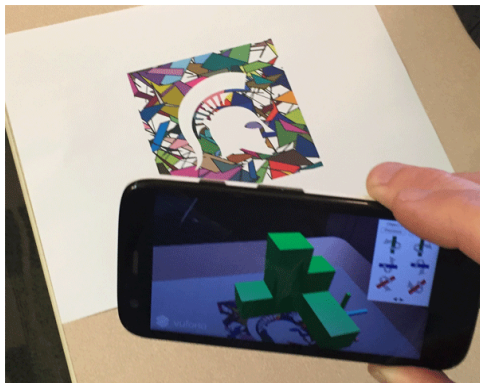

Figure 1: Augmented reality based on a printed target (marker)

The app included what was essentially a stand-alone course in spatial visualization based on a set of digital objects. The use of the app was required within the course, yet there was only a loose association between the lessons in the app and the lessons in the class.

The digital objects in the app included simple abstract objects, everyday objects, and more complex abstract objects (see Figure 2). As students made progress in the app, and as the time in

the course progressed, additional objects and additional forms of interactions with these objects became available to the students.
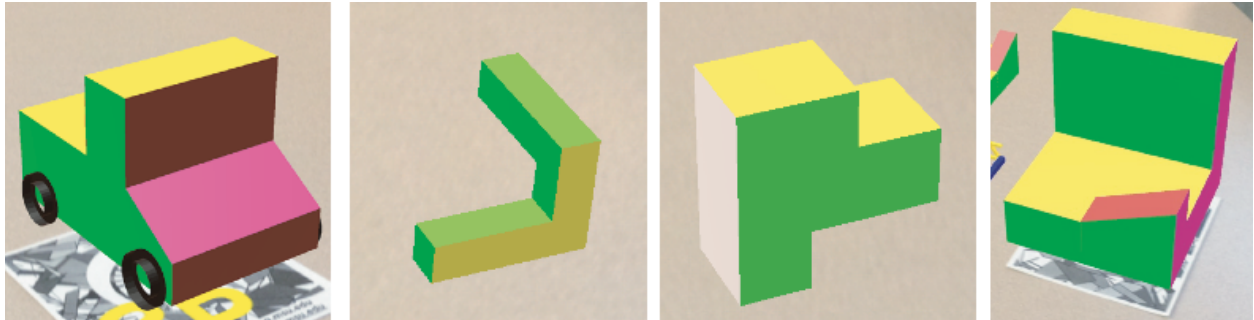

Figure 2: Sample of the digital objects in the augmented reality app

Multiple games were created that included "free play" (no particular answers or performance was required), graded tests (they could proceed whether or not they got the right answers), and activities that required correct answers before they could proceed. See Figure 3 for examples of various games and activities that were included.
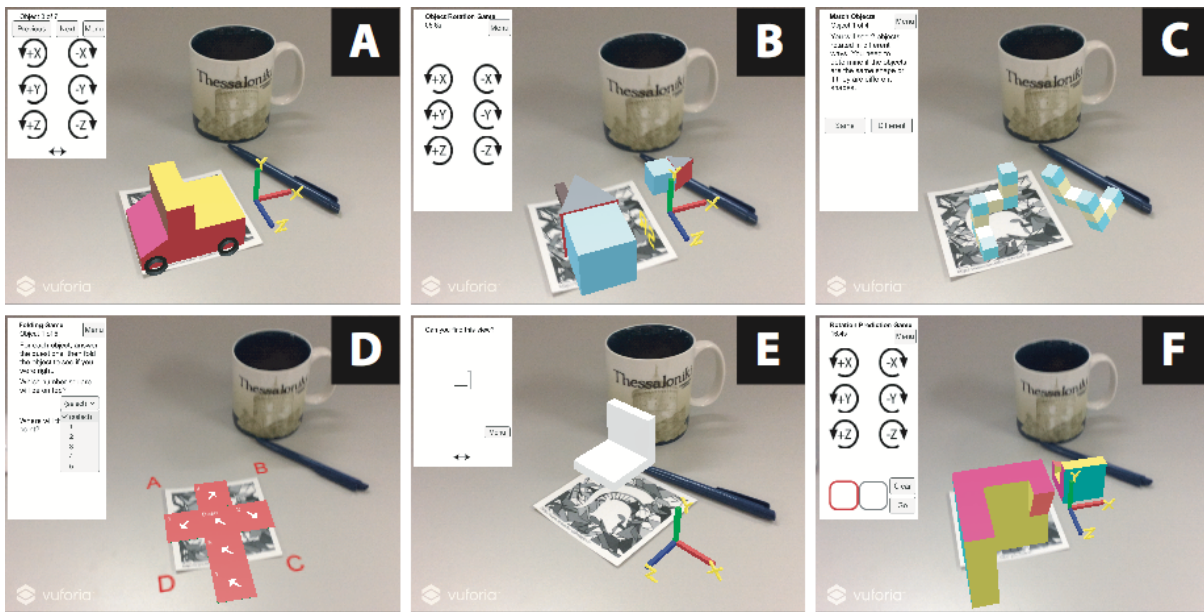

Figure 3: Various games and objects in the augmented reality app

Bell, et al. [18] hypothesized that limited time in an augmented reality app might explain the minimal benefits of the app. Since a key question for this study was whether or not additional time in using an augmented reality app might lead to greater benefit, the app was designed to promote longer engagement. Key features included:

- Ranking players to show high scores
- Comparing a player's score with one's own scores
- Rewarding additional play of games with tokens within the app

Research Questions

The research questions of this study were:

- Does extended time in a handheld augmented reality app lead to greater spatial reasoning gains than taking a conventional class alone?
- What effect do the features of the app, designed to encourage extended meaningful use of the app, have on student use and their attitudes about the app?

We employed a mixed methods approach, including the quantitative measures of pre/post test scores, app usability, and student responses to pre and post intervention surveys.

Context and Method

This study was implemented among first-year students at a major Midwestern university. All new students who indicated an interest in engineering were required to take the PSVT:R assessment of mental rotation. Those who scored below 60% were encouraged to take a 1-credit course, similar to that described by Sorby [3]. In total, 1494 students took the assessment. Of that group, 326 scored below 60% and thus were recommended to take the course. In the end 68 students took this course. This course had 4 sections, two on Tuesdays, and two on Wednesdays (for student distributions, see Table 2). On both days, the sections each met for a 50-minute session at 4:10pm and 5:20pm. The demographics of the subjects are shown in Figure 4.
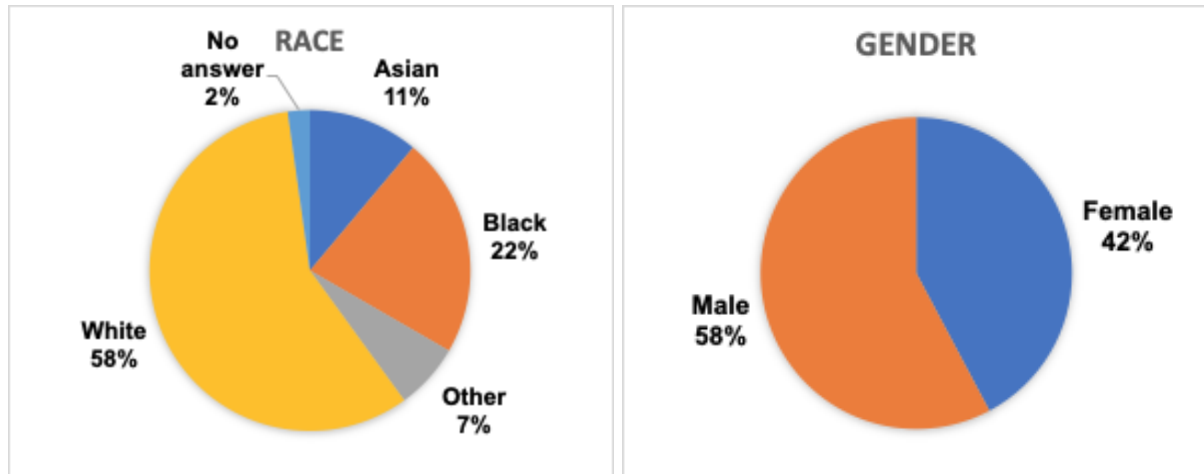

Figure 4: Demographics of subjects

The control group included the two Wednesday sections, and this group followed the Sorby curriculum very closely [3]. Because these sections were small, quite a bit of 1-on-1 interaction with the instructor and class assistant was possible. The experimental group followed the same curriculum as the control group, with the addition of the use of the app. Students were required to complete the app, with the repetitions required to earn stars on all of the lessons, in order to get full credit on their homework. The only in-class time that was different between the experimental and control conditions was in the first two weeks during the installation and initial use of the app. The primary context for the intervention was during student homework time on their own.

Results

As shown in Figure 7, students spent over 5 hours on average using the app over the semester. This time is comparable to the time spent on some other interventions that have been shown to

have benefit for developing spatial reasoning [4], and is several times greater than what was reported for a prior study of the use of an augmented reality app [18].

	Max	Min	Mean	Median	StdDev
Hours	15.9	0.1	5.4	5.8	3.56

Table 1: Student hours in app

To answer our first question, namely, whether extended time in a handheld augmented reality app led to greater spatial reasoning gains than taking a conventional class alone, we did a quantitative analysis of the change in test scores on the PSVT:R assessment.

The first question is whether or not there was 'extended time' in usage of the app. As shown above (see Table 1), the use of the app for over 5 hours was considered a reasonable amount of time for the effect of the app to be known.

Our analysis shows that there was significant growth over both conditions; the 1-credit course led to significant gains (correlation=.340, p=.017, see Tables 2 and 3). Although there was no significance in the benefits gained in the use of the app, it is reasoned that our sample size was too small to accurately assess learning gains between such small sections. Additionally, the variation between student growth scores and the small section sizes may have masked the gains that came through the app (see Table 2).

Group	Section #	N	Mean growth
Experimental	1	23	10.22
	2	7	6.86
Control	3	9	9.89
	4	6	5.00
	Total	45	8.93

Table 2: Overall effect comparison (experimental/control)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pre	13.44	45	2.904	.433
	Post	22.38	45	4.292	.640

Table 3: Paired samples statistics

At the same time, there was a surprising difference between the early and late sections of the course. That is, the 4pm sections showed significantly greater growth, when compared to the 5pm sections (p=.006). We don't have an explanation for this, although it is consistent with classroom observations regarding student engagement and effort. It is possible that other factors affected the population of students who were enrolled in the early and late sections.

In terms of gender effect, there was no overall effect of gender across both control and experimental groups. That is, male and female experience comparable gains from the course.

On the other hand, females experience a significant benefit from using the app. See Tables 4 and 5 for female scores. Note that there was no significant difference in pre or post scores overall

between males and females. On the other hand, for males, no significant benefit was found from the use of the app as compared to the control condition.

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
Change	Control	5	6.40	2.793	1.249	2.93	9.87	4	11
	Exp.	12	9.92	3.204	.925	7.88	11.95	5	16
	Total	17	8.88	3.426	.831	7.12	10.64	4	16
Post	Control	6	21.33	4.719	1.926	16.38	26.29	16	28
	Exp.	13	22.92	3.095	.858	21.05	24.79	18	28
	Total	19	22.42	3.626	.832	20.67	24.17	16	28
Pre	Control	5	14.00	3.000	1.342	10.28	17.72	11	17
	Exp.	12	13.42	2.314	.668	11.95	14.89	9	17
	Total	17	13.59	2.451	.594	12.33	14.85	9	17

Table 4: Comparison of control and experimental conditions for females

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Change	Between Groups	43.648	1	43.648	4.543	.050
	Within Groups	144.117	15	9.608		
	Total	187.765	16			
Post	Between Groups	10.375	1	10.375	.780	.390
	Within Groups	226.256	17	13.309		
	Total	236.632	18			
Pre	Between Groups	1.201	1	1.201	.190	.669
	Within Groups	94.917	15	6.328		
	Total	96.118	16			

Table 5: Significance of greater growth in experimental condition for females

There was no significant difference in interest or enjoyment between the experimental and control groups, either for the overall group or for males or females alone. There was a significant decrease in enjoyment overall (pre=3.59 on a 0 to 6 point scale, post=3.01, p=0.001). This decrease in enjoyment was not significantly different between the control and experimental groups.

There was a significant growth in interest overall (pre=2.74 on a 0 to 6 point scale, post=4.05, p=0.00).

Qualitative Analysis

To answer our second question, namely, what effect the features of the app designed to encourage extended meaningful use of the app had on student use and their attitudes about the app, we did a qualitative analysis of student comments in the experimental group. Student comments were collected through a survey at the end of the class. They were asked to give positive feedback,

negative feedback, and suggestions for improvement. They are presented briefly here, with sample statements to illustrate what we found.

On the positive side, there were many comments about the benefits of the realism offered by augmented reality. Several students noted how the app allowed them to 'visualize easily" and see how objects rotate in space. The 3D elements were also highlighted numerous times, providing a clear view of both object characteristics and rotations. Furthermore, students repeatedly favored the ability to visualize objects from different angles and perspectives.

Students also commented on the benefits of the immediate feedback on their actions and the answers. One student wrote: "I could attempt the problems and see where I made errors." Another described how it was helpful to visualize rotations in real time.

The negative comments from students helped explain the lack of enjoyment in these activities. The most common response was an expression of dislike for the required repetitions in order to earn full credit for homework. Students often noted frustration with the high volume of required repetitions. This was both related to the requirement to perform repeated tries for the same task and the number of tasks required in a given topic.

It is not surprising that the students then gave suggestions to provide more variety in the app. For example, many students suggesting providing greater variation in the objectives and assignments.

Another important theme was dealing with bugs in the app. This app was a custom development project by our team, and we realize now the challenges of making an app that works on many different generations of both Android and iOS devices. This caused fatigue for users who were locked out of the app or ran into impassible obstacles for sometimes hours at a time.

It seems that a few people had trouble understanding the use of the target and how it supported the augmented reality. In particular, one student completely misunderstood the app procedures and couldn't get it started.

Discussion

When considering the value of this app, it is important to recognize the finding that the course, in both of its models, led to significant improvement in performance on the PSVT:R. In addition, students grew in their interest in spatial reasoning activities because of this class.

In terms of our first research question (Does extended time in a handheld augmented reality app lead to greater spatial reasoning gains than taking a conventional class alone?), we did not find an overall benefit when students used the app a total of multiple hours. (Although our limited participant numbers may have been the primary reason.)

The second question (What effect do the features of the app designed to encourage extended meaningful use of the app have on student use and their attitudes about the app?) is best answered based on student comments. In short, their increased time was seen as repetition without value, and the features added to support this increased time (earning stars and competition with self and others) were apparently ineffective or insufficient for making this extra time satisfying or valuable. It is clear that merely increasing time is not a sufficient to ensure the value that extra time might bring.

The most valuable aspect of the app is the value found for females. That is, there was significantly more growth among females who used the app as compared to those in the control group. Given the relatively small sample size and the large variation between sections, as well as the known problems in the app, this finding suggests that something important is happening in support of females who have been reported to do more poorly on spatial reasoning assessments [19]. It is also consistent with the finding of [15] that augmented reality overcame the disparity for females found in a conventional classroom setting alone.

In terms of next steps for research, there seems to be sufficient evidence of the benefits of augmented reality to continue the exploration. Of greatest significance, the benefit experienced by females, even in this small sample, suggests that augmented reality allows for a different way to engage with these skills that might be helpful for underrepresented populations in STEM disciplines. At the same time, it is clear that the details of implementation of augmented reality are important. Bugs in the app, as well as the imperfect efforts to build in features that would promote more meaningful engagement in the app, show the importance of high quality design and implementation of technology tools for learning and research.

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