The Efficacy of Augmented Reality in the Classroom

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Abstract

My senior year capstone project consisted of an iOS application utilizing augmented reality (AR) in teaching students the processes of photosynthesis. An emerging technology made popular recently through applications such as Nintendo's mobile game *Pokemon Go* and IKEA's *IKEA Place*, augmented reality makes use of a device's camera to overlay 3-dimensional graphics and images onto the device's screen to draw a composite image. Stemming from previous research positively correlating student engagement with student performance, I used the application I've built to assist students in learning while making use of this new and interactive technology. In doing so, I measured student learning through pre- and post-tests, and determined the usefulness of augmented reality in the classroom when compared to more conventional and less-interactive learning methods.

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1 Introduction

From a very long-term study done by the National Assessment of Educational Progress and coordinated by the US Department of Education, data showed that since 2015 average math scores among 4th and 8th grade students had once again begun to decline; not having done so since 1990 [4]. After reading multiple articles in CSC-497, I discovered papers that were able to positively link a student's engagement in class - that is, their interest in a particular subject - and their academic performance in that specific subject. In 2006, Carini et al. [3] conducted a study on college students that paired questionnaires with analysis of the students' scores on the RAND tests, scores on the GRE, and their overall GPA. Additionally, Marks [10] argued that increased engagement in class leads to stronger academic performance, touching on an article by Finn [6] before stating that "students [...] are more likely to learn, to find the experience rewarding, to graduate, and to pursue higher education" when more interested and involved in school.

Figure 1: Examples of augmented reality applications in use [14].

When I came across the medium of augmented reality, I began to wonder if there exists a way to possibly improve a student's engagement in a topic and therefore their grades. Augmented reality (AR) is a blending of digital images into the real world, described as "an enhanced image or environment as viewed on a screen or other display, produced by overlaying computer-generated images, sounds, or other data on a real-world environment" (see Fig. 1) [5]. After some research, I reasoned that AR would lend itself very well to a classroom environment for three main reasons: (1) the technology is engaging, (2) it works well with layered / hierarchical systems, and (3) there is already a precedent for using AR as a data visualization method. Additionally, building an AR application could have the effect of "gamifying" the subject, effectively "lower[ing] test anxiety and increas[ing] engagement" among students, as seen by Kiili and Ketamo [9] in their study using a small iPad game as a manner of testing students' knowledge of fractions.

Since augmented reality is a relatively new technology, students would likely be much more interested to see their subject matter represented in a format aside from a diagram or a textbook - as discussed in a 2009 research paper from Harvard stating that the use of augmented reality "enhances student motivation, involvement, and engagement" despite not even having the proper technology to display AR applications

[11]. Since today's AR technology was not available then, this study made use of small computers with GPS tracking devices, encouraging the students to wander around their school building to learn about different topics. Due to their technology limitations, they experienced some difficulty regarding ”hardware and software issues, ... [and] GPS errors,” but were still able to conclude that an augmented-reality enabled lesson yielded high levels of engagement and motivation [11]. On top of that, in the years since that article was written, the use of augmented reality has increased dramatically - where it is currently a trending topic in the phone app development industry; so much so, that industry experts estimate the market for AR will grow to a surprising 120 billion USD by 2021 [1]. Additionally, companies such as Intel and Google have already been working on technologies to allow users to make use of augmented reality on the go, as both tech giants have developed eyeglasses that display information directly into the users' eyes, showing notifications or map directions as needed [2].

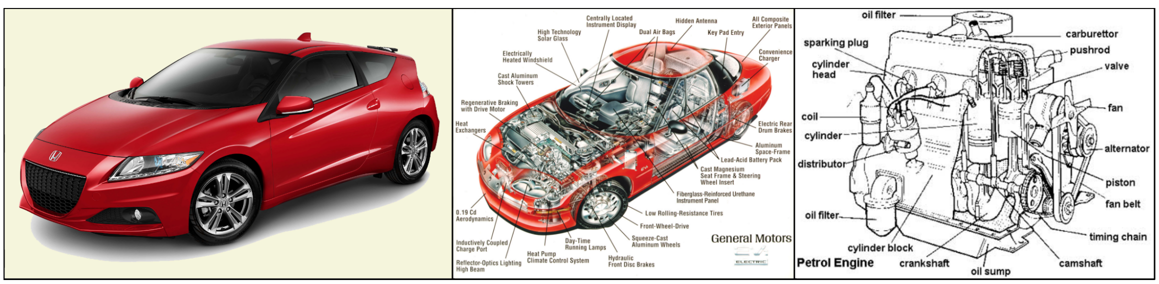

Figure 2: Example of a hierarchical system that could be displayed through AR

Due to the manner in which AR is displayed, by portraying computer-generated objects as though they exist right in front of the user, it lends itself very well towards use in displaying layered or hierarchical systems. For example, in Figure 2 a user can place a car (left) onto a table in front of them, allowing them to see what the machine looks like from the outside, and possibly how it acts while running. Through augmented reality, the app can be designed to allow the user to treat their phone as though it is a high-powered magnifying glass: a user might be able to use this app to take a step closer to the car and peel away the metal plating which hides the complicated components and systems "underneath the hood" (middle). Even further, the user can then move the camera closer, and choose to focus on one system to study, for example the engine (right). By allowing this, the app lets the user visualize how the entire car functions overall, how the components within the car work together to run the vehicle, and how each individual component works on its own. This method of displaying hierarchical systems gives the user total freedom to analyze what they feel as though is necessary to learn, while portraying the entire system as it would operate in the real world.

By using augmented reality, users have access to a more realistic representation of objects via 3D computer graphics, as they are able to visualize or manipulate objects in ways that were once only feasible through a strong imagination. Given this, the same might be attainable through a simple on-screen animation; however through the use of AR, users are given the opportunity to experience how the subject matter works and operates as though it physically exists right in front of them. Furthermore, AR does not restrict the user's environment to the boundaries of a computer screen - it gives users the ability to explore the information in a manner that's most intuitive to them. Whether they want to just look at the outer appearance of the car, or the intricacies of an engine, the user can visualize any aspect of the information that they choose just by moving around a room. According to Hannes Kaufmann [8] "spatial abilities present an important component of human intelligence;" meaning that by having the opportunity to more realistically represent objects in a 3D space, it becomes much easier to understand and interpret how those objects or concepts function. In other words, utilizing augmented reality to teach students, can have the added effect of improving the students' perception of the topic.

2 Design Requirements

When I began to think about possible topics to represent in my application, I realized that photosynthesis would be a great example to display via augmented reality since - like the car example from above - it involves the multiple working parts, or subsystems, of a plant. On the outer, basic level, plants take in sunlight, carbon dioxide, and water to produce energy for themselves while also releasing oxygen as a byproduct. While most students may possess this basic understanding of photosynthesis, there are deeper levels to the process that could be better explained by "zooming in" further into the actual cells of the plant.

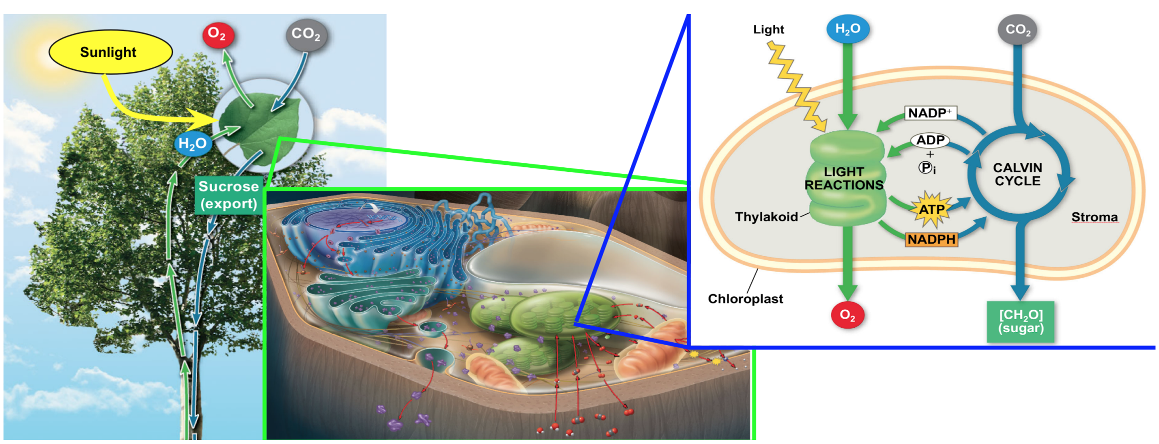

Figure 3: Diagram of the 3 levels of photosynthesis used in the application

At a cellular level, the majority of reactions within the photosynthesis cycle occur within the chloroplasts in each plant cell. The chloroplasts are what take in the particles mentioned earlier (light, water, carbon dioxide), and use them to interact with other organelles such as the nucleus or the mitochondria. Inside each chloroplast, there are two major components: the grana, which are stacks of structures called thylakoids, and the stroma, which is a fluid surrounding the grana. The thylakoid stacks absorb the light energy from the sun and the water (H_2O), which they use to output oxygen (O_2) into the air and transfer ATP and NADPH into the stroma. However, the grana also require $NADP^+$ and ADP to generate those products. ATP and ADP effectively serve as phosphate transport systems to bring energy from the thylakoids to the Calvin Cycle, while NADPH and $NADP^+$ are used for transporting hydrogen ions between the two components. Within the stroma, a process called the Calvin Cycle takes in carbon dioxide (CO_2) from the air and the ATP / NADPH from the grana to generate both glucose as food for the plant, and ADP / $NADP^+$ for the light-dependent reaction within the thylakoid stacks (see Fig. 3).

Without very advanced scientific tools which could cost thousands of dollars, a beginner biology student would not have an easy way to view processes involving the transfer of molecules that occurs during photosynthesis. By taking advantage of augmented reality in situations such as these, students are able to simulate the hands-on approach provided in a research laboratory, as though the process is being carried out right there, in-person.

Before developing my application, I conducted some research into the possible software and plugins that would be most beneficial to my project. On the graphical end, I already had access to the **Adobe CC Suite** - both personally and through the digital art lab - and a free student license for **Maxon Cinema4D** (C4D) (Fig. 4, left) through my 3D Modeling course at Union. These programs are optimal for 3D modeling and creating graphics to be used later, but there are also multiple free image editing and 3D design programs available online such as GIMP and Blender. However, it is important to note that each of these programs are not completely intuitive to use, and it is recommended to follow some online tutorials prior to use.

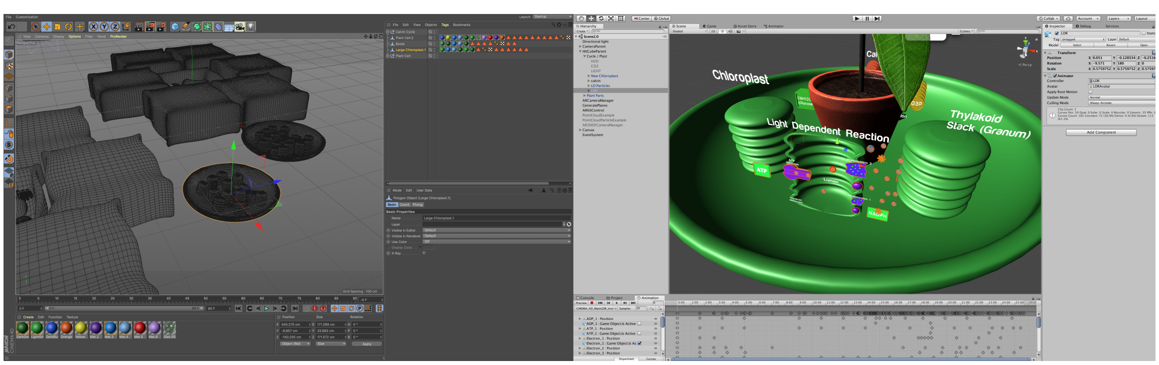

Figure 4: Screenshots of Unity and Maxon Cinema4D - software used in building the application and creating 3D models of the cell

In addition to Photoshop, Illustrator, and C4D, I used the game development platform **Unity 3D** (Fig. 4, right) in conjunction with the iOS development IDE **Xcode** and Apple's new **ARKit** tools. I used Unity to do most of the programming and setup of the application, while Xcode essentially served as a middleman, with Unity building the application, transferring the output from Unity into Xcode, and then used Xcode to compile and install the application on the device itself (in my case, an iPhone X). Since ARKit can only run on iOS 11 enabled devices, it was important to make sure I could run the application on one of my devices first. Additionally, in the beginning of the term I needed to download and install beta versions of Xcode and iOS 11, since they had not yet been released to the public at the time. Finally, to use Unity effectively, I had to write scripts in the C# programming language (although JavaScript is also an option) to manage some aspects of objects within the application.

3 Design

To begin implementing my project as an iOS application, I began to research into how to develop for iOS in the first place. While iOS development is nothing new, the technology I wanted to utilize was only introduced in June 2017. Quoted as being "the biggest thing that's happened to the AR industry since it began," Apple's ARKit technology is "poised to become the world's most powerful and popular purveyor of augmented reality apps" just from the sheer audience the technology reaches alone [12]. Before ARKit was announced at Apple's developer conference (WWDC), there very few augmented reality resources available to use, with only two being the most successful, *Vuforia* and *ARToolkit*. Because of this, I found myself struggling on some occasions to find ARKit-related information or guides that I could use to learn from. The majority of the tutorials I found online were either for older software or other platforms. However at the end of the summer, I found out that the developers at Unity released a plugin for their software to seamlessly integrate Unity3D, Apple's ARKit, and Xcode (available on the Unity3D Asset Store) [13]. As mentioned earlier, I also had to ensure that I was using the most current versions, and in some cases beta versions of the software. Finally, despite having all the correct programs installed, I needed to set up a free Apple developer's license, so that Xcode would allow me to push the application to my iPhone. These beta versions were necessary for me to use, since at the time of development, none of the ARKit-related tools had been released publicly.

3.1 Programming

At the start of fall term I planned on using strictly Xcode mixed with ARKit, and not building the project by using Unity3D. Because of this initial idea, I would have had to learn an entirely new programming language, Swift. Not being completely comfortable with both the IDE and the the language it used, I decided to look back into Unity as a vessel to develop my capstone project. Unity was a very helpful piece of software for this project, as it not only offered tutorials written by its own developers, but was relatively quick to pick up and easy to use. On top of its intuitiveness, Unity is also very adaptive, in the sense that it can read multiple file formats, which allowed me to make use of the set of different graphic design programs listed earlier.

Although Unity is formatted as a game development tool, it is very versatile and isn't limited to video games. The software allows users to create containers called "game objects" which can control the placement and functionality of each of the 3D models and graphics on screen. Each game object has parameters or tags attached to it, ranging from its position on screen to hand-written C# or JavaScript code snippets, which I created to add effects such as hiding and showing segments of the plant as the user moves the device closer to the model. While I did need to re-learn how to write in C# and how to use the Unity3D C# libraries, it was much more of a feasible task for me, since I already have had some experience in using Unity and since C# is an object-oriented language somewhat similar to Java, which I am very comfortable using. Even in the cases where I was not completely sure how to approach building my application, I found that there is an abundance of tutorials online with respect to using Unity, and they proved to be immensely useful despite not all being directly about using the platform for augmented reality (see Hallberg [7] for a starting point).

3.2 Graphic Design

While most of the back-end development of the application was done through Unity, a large portion of my time was also spent using Cinema4D and Adobe Illustrator to generate 3D models and scalable vector graphics for use on the front-end of my project (see Fig. 5). To be able to portray the processes of photosynthesis in the manner that I wanted, I needed to model each microscopic aspect of the chloroplast so that users were able to see how each component was used in generating the products such as oxygen and sugar / energy.

In order to export the models from C4D into Unity, I had to save the selected model as an .FBX file, since the standard .C4D files can not be interpreted properly by Unity. From there, all I needed to do to access that file was open my Unity project and import the .FBX file into my assets folder. Since the 3D

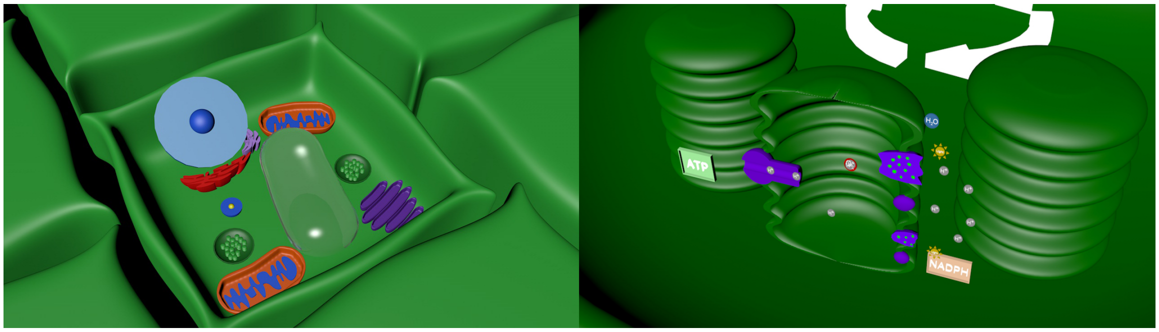

Figure 5: Models of the plant cell and chloroplast created within Cinema4D

models are comprised of multiple small parts, it was technically a group of tiny models under a parent object as opposed to one larger, connected model. Because of this, when importing the model into Unity, the program treated it as a group. The issue with handling the models this way is that when I wanted to show and hide a model, for example, I had to apply the fade in/out script to the parent object and all of its children. This still achieved the same effect, but just required more work to implement each time I needed to change a script or characteristic of the parent game object.

3.3 Application Design / User Experience

For the overall design of the application, I wanted the user to be able to zoom in and out by moving the device, as though their camera is a magnifying glass through which you can see inside a plant's cells. As the user zooms closer from the outer view (Fig. 6, left), the plant should disappear revealing the chloroplast (Fig. 6, middle). In this view, the user is free to examine all of the parts within the chloroplast. From there, the user can move the camera even closer to get a better view of certain processes within the organelle (Fig. 6, right). Since all the parts of the chloroplast are visible to the user, the design of the app gives them freedom to experience how the components work separately, or as a whole - similar to the example described earlier.

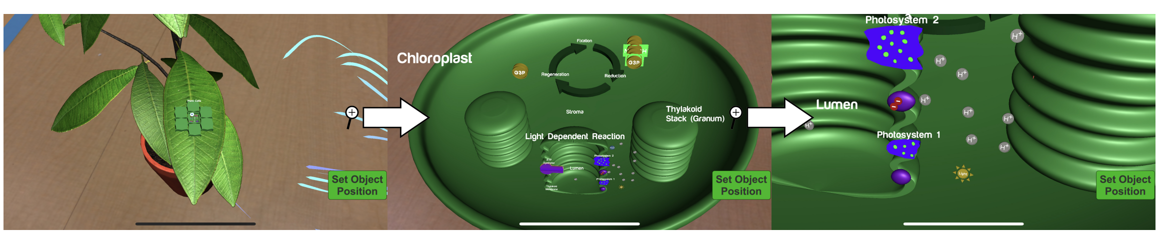

Figure 6: Screenshots from within the app, displaying three levels of zoom

To accomplish this effect, I wrote a C# script, *fadescript.cs* (see appendix), to adjust the visibility of an object and its children based on wether or not the user has made a motion to zoom in or out of the 3D model, to display the second level (Fig. 4, middle and right).

Visible in the middle image of Figure 6, once the user has zoomed in they are able to visualize the particles of ADP, ATP, NADPH, and $NADP^+$ as they are transferred between the thylakoid stacks and the Calvin Cycle. Initially, these were somewhat hard to coordinate; each particle you see on-screen was set up as a 2D, flat image before I decided to re-do the models and make 3D models of each particle. Due to the nature of Unity's game objects when they're imported from Cinema4D, it was challenging to coordinate the movement of each particle if they needed to move in any manner other than in a straight line. To get around this issue, I created the animations in Cinema4D as well, and brought the moving objects in, with the animations included.

3.4 Experiment Design

The last step in designing my project was the experiment itself. The subject testing took place during the middle of winter term, where I aimed to collect data from around 30 subjects. However, I was only able to recruit 10 students to participate. To carry out my study, I signed up for blocks of time in Union's Human-Computer Interaction lab, a room designed with desks and seating for a subject to sit at, and with one-way mirrors so that I could observe as the subject partakes in the study.

To start, the students were divided randomly into two evenly-sized groups to determine what learning resource they had access to following the pretest. In the trial, each student (in both groups) was administered a pretest quiz in order to determine prior levels of knowledge of the subject, photosynthesis. Following the pretest, students moved on to the next step where they were allowed as much time as necessary to study from the supplied material. For the study material, one group had access to a photosynthesis "cheat sheet", while the second group had access to both the cheat sheet and the application that I developed.

When selecting information to include on the sheet and in test questions, I reached out to Professor Rice and Professor Pytel in the Union Biology Department for guidance - I wanted to be sure that my questions and study material were not biased in favor of my application. The students then had as much time as necessary to study their given resources until they feel comfortable enough to take the post-test quiz; I chose to not apply a time limit to any of the activities, so that I can use that as another data set (the amount of time the student spent on each task). Students were able to ask questions, however I only provided them with answers if the question pertained to using the application or finding material within their given resource. I made sure to not give them answers to questions regarding the subject matter itself, as I wanted all learning to come from the given study material. Finally, once the subject felt comfortable enough with the material, I administered a posttest to assess how much they had learned from their time in the study.

The questions on the posttest were the same as those on the pretest so that I could ensure I was comparing results from the same questions. In order to avoid bias related to having the same quiz twice, the subjects were not told that there would be a second test until after their study period (to prevent subjects from attempting to memorize questions).

As mentioned before, while the students spent time working on the tests and studying, I kept a log of how much time was spent on each. Accompanying that data, I also collected the scores of students on both the pretest and posttest so that I could analyze performance and score improvement between tests. Lastly, I made use of the screen recording feature available in Apple's iOS 11 to be able to break down the time spent between the app and the cheat sheet, for those who had access to both.

4 Project Budget

When applying for a grant, I planned to pay my subjects $8 for their participation, as I anticipated each trial might run for - at most - one hour, depending on how long the student spends completing each segment of the study. I hoped to receive approximately 30 study subjects, so the total estimated cost would amount to $240. I was fortunate enough to receive a grant for $190 from Union's SRG committee, and $50 from the Computer Science Department. However, after finalizing my experiment design, I realized the study would only last at most 30 minutes, and therefore only need to pay $5 per subject. Due to my lack of subjects, I ended up only giving out $50 of my granted funds, and returned the remainder back to the committee.

5 Results

5.1 Descriptive Statistics

Measurement	N	Mean	Std. Deviation	Min	Max
Quiz 1 Time	5	5 min, 42 sec	1 min, 19 sec	3 min, 26 sec	6 min, 43 sec
Study Time	5	10 min, 3 sec	5 min, 33 sec	4 min, 45 sec	18 min, 11 sec
Quiz 2 Time	5	3 min, 49 sec	30 sec	3 min, 2 sec	4 min, 27 sec
Test Time Decrease	5	1 min, 54 sec	1 min, 23 sec	-29 sec	2 min, 55 sec
App Study Time	5	5 min, 32 sec	3 min, 31 sec	1 min, 55 sec	10 min, 34 sec
Cheat Sheet Study Time	5	4 min, 31 sec	3 min, 24 sec	2 min, 35 sec	10 min, 31 sec
Test 1 Scores	5	9 points	2.54 points	5 points	11 points
Test 2 Scores	5	10.6 points	3.36 points	5 points	13 points

Table 1: Study Results - Descriptive Statistics - AR Group

Measurement	N	Mean	Std. Deviation	Min	Max
Quiz 1 Time	5	4 min, 33 sec	1 min, 12 sec	3 min, 25 sec	6 min, 9 sec
Study Time	5	4 min, 11 sec	3 min, 35 sec	1 min, 15 sec	10 min, 24 sec
Quiz 2 Time	5	3 min, 12 sec	37 sec	2 min, 34 sec	4 min, 6 sec
Test Time Decrease	5	1 min, 21 sec	46 sec	36 sec	2 min, 35 sec
App Study Time	5	0 sec	0 sec	0 sec	0 sec
Cheat Sheet Study Time	5	4 min, 11 sec	3 min, 35 sec	1 min, 15 sec	10 min, 24 sec
Test 1 Scores	5	11.4 points	1.34 points	10 points	13 points
Test 2 Scores	5	10.6 points	3.36 points	12 points	15 points

Table 2: Study Results - Descriptive Statistics - Non-AR Group

5.2 Analysis

After carrying out as many subject studies as I could organize, I arranged my data into three main comparisons that I deemed relevant to my research question:

1. Pretest score vs. Posttest score (Score improvement)

2. Time spent studying using AR vs. Using the cheat sheet (Study time allocation)

3. Time to complete pretest vs. Time to complete posttest (Test time decrease)

To help measure all of my data, I ran a series of paired, 2-tailed t-tests so that I could compare the performance of two separate groups that took the same tests. On both of the tests, there were 15 questions, each worth one point. To no surprise, all study subjects improved by an average of 2 points from their first test after going through a study period. Unexpectedly though, students who had access to the AR application only improved an average of 1.6 points after studying, whereas students without the application improved by an average of 2.4 points. While this result was surprising to me, the one outlier among the participants skewed the results so much that it decreased the average improvement by over a whole point. With the outlier removed, the average score improvement of students with the app was 2.75 points. Nonetheless, these results were statistically insignificant, as seen in Table 3 below.

Total Possible Score	Average Score Improvement (AR)	Average Score Improvement (Non-AR)
15 points	1.60 points	2.40 points
P-value = 0.5964		

Table 3: Study Results - Test Scores

The second aspect of the study that I analyzed pertained only to the group of students with access to the AR application: the time spent using the app versus time spent using the cheat sheet. This data was collected by making use of the screen recordings from the iPhone, where I was able to see how long the section of video was that showed them using the AR app. The average student in this group spent 10 minutes and 3 seconds studying, with an average of 5 minutes and 32 seconds on the AR app, and 4 minutes and 31 seconds on the cheat sheet (see Table 4). These results were significant, and point towards the possibility of students spending more time using the app due to its engaging characteristics. It is important to note that this outcome could be due to the application being more time-consuming or hard to use. However, gauging the responses from student feedback, the majority felt as though the app was useful. As mentioned before, this statistic would be much more substantial given more subjects.

Average Time Studying with App	**Average Time Studying Cheat Sheet**
5 minutes, 32 seconds	4 minutes, 31 seconds
P-value = 0.0243	

Table 4: Study Results - Study Times (AR Group Only)

When looking at the times students took to complete tests, I discovered that students completed their posttest an average of 1 minute and 37 seconds faster than their pretest. However, when comparing the results between the two groups, I found that students with access to the app completed their posttest an average of 1 minute and 53 seconds faster than their pretest, whereas students without the AR application only saw a decrease of 1 minute and 20 seconds. Although these results suggest that students may complete exams quicker after studying with the app, t-test (see Table 5) suggests that the data is inconclusive.

Average Time Decrease between Pretest and Posttest	
AR Group	**Non-AR Group**
1 minute, 53 seconds	1 minute, 20 seconds
P-value = 0.0855	

Table 5: Study Results - Test-Taking Time Changes

One last question I asked while looking at my results was whether or not the time spent studying with the AR app had an effect on how that student's score improved from the first test to the second. To my surprise, as seen in Figure 7, the time spent using the app seemed to have a negative impact on how much the student improved score-wise between the first and second tests. However, this figure also displays the data from the outlier mentioned earlier, and seems to highlight the fact that having more subjects would clarify my results further.

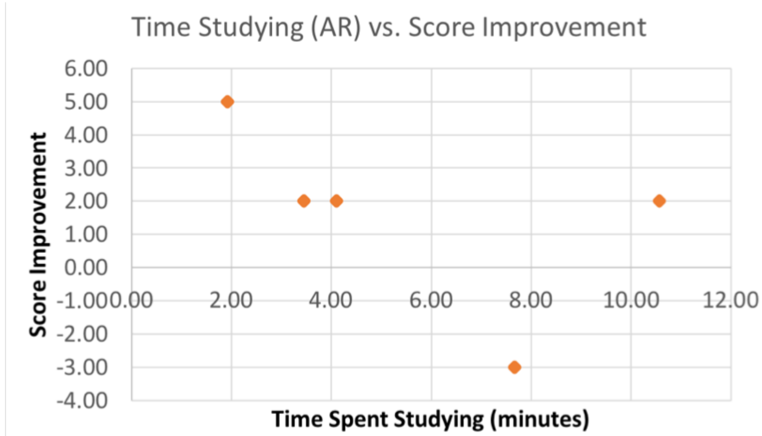

Figure 7: Chart comparing time spent studying (using AR) versus score improvement

5.3 Future Work

Overall, I recognize that having only 5 subjects in each study group is a very small sample size to produce credible results. Therefore, despite some results reading as statistically significant, my study needs more subjects to present data that is more concrete. Additionally, now that my study has concluded, I believe there is still room for improvement in my experiment design. Despite having its advantages over a video or animation, I believe that it would help to add a third group, or incorporate a comparison between my application and a video explanation of the same topic. This would help me differentiate the benefits of one medium over the other. In addition, it would have helped to administer a questionnaire at the end of the study to gauge how students feel about using the application, and to have written proof of this (as opposed to just hearing what the subject comments on afterwards). This data wouldn't exactly be quantifiable, as it might be a matter of preference versus actual performance, but it would also help justify whether or not the app is actually engaging, or if it is just time consuming to use.

6 Conclusion

In summary, my capstone project has been a great learning experience for me, learning both how to build an augmented reality application from scratch and the possible effects it may have in a classroom environment. Drawing from the three measurements I discussed in the results section, I found that both the study time allocation and test time decrease data spoke in favor of using AR as a study tool, while the score improvement measurement favored otherwise, as seen in Table 6:

Measurement	Favors	Statistically Significant?
Score Improvement	Non-AR	No
Study Time Allocation	AR	Yes
Test Time Decrease	AR	No

Table 6: Study Results - Summary

In addition, the only statistically significant metric was the comparison of study time allocation between the cheat sheet and the application. Based off these results, my data suggests that augmented reality may be more engaging than studying using more standard mediums. However, I cannot confidently say that this increased engagement in AR can be linked to an actual performance improvement due to having such a small sample size - many more subjects will be needed to clarify my results.

Appendices

A Acknowledgements

I would like to thank Dr. George Bizer, chair of the Psych dept. at Union and Dr. Catherine Snyder, chair of the Department of Education at Clarkson University, Capital Region Campus for their assistance in determining methods of testing my research question. I reached out to both professors for information on assessing student learning, and methods of doing so. In addition, I would like to thank Professor Rice and Professor Pytel from the Union Biology Department for their consultation on the correctness of my application and for allowing me to recruit students from their introductory biology courses to take part in my study. Finally, I want to thank my advisor, Chris Fernandes, for his assistance and guidance throughout the course of my thesis project.

B fadescript.cs

Snippet from *fadescript.cs*, a short script used to change the visibility of objects depending on their distance to the camera:

```
...
// Update is called once per frame
  void Update () {
    float distance = Vector3.Distance(this.transform.position, gameCam.position);
    if (isVisible){
      if (distance < minRange){
        if (hasZoomed) {
          foreach (var r in renderers){
            r.enabled = false; //disables r, the renderer of each child object
          }
          foreach (Renderer r in oppRenderers){
            r.enabled = true; //enables r, the renderer of each child object
          }
        }
        else{
          foreach (var r in renderers){
            r.enabled = true;
          }
          foreach (Renderer r in oppRenderers){
            r.enabled = false;
          }
        }
      }
      else if (distance > maxRange) {
        if (hasZoomed){
           hasZoomed= false;
        }
        else{
          hasZoomed = true;
        }
      }
    }...
```

References

[1] Ali Ash. *The Rise of Augmented Reality Technology In a Virtual Reality World*. 2017. URL: https://www.business.com/articles/the-rise-of-augmented-reality-technology-in-a-virtual-reality-world/.

[2] Mike Brown. *Smart Glasses Are Back: How Intel Vaunt Stacks Up to Google Glass*. 2018. URL: https://www.inverse.com/article/40998-google-glass-vs-intel-vaunt.

[3] Robert M. Carini, George D. Kuh, and Stephen P. Klein. "Student Engagement and Student Learning: Testing the Linkages". In: *Research in Higher Education* 47.1 (2006), pp. 1–32. URL: https://link.springer.com/article/10.1007\%2Fs11162-005-8150-9?LI=true.

[4] Drew DeSilver. *U.S. Students? Academic Achievement Still Lags That of Their Peers in Many Other Countries*. 2017. URL: http://www.pewresearch.org/fact-tank/2017/02/15/u-s-students-internationally-math-science/.

[5] "Dictionary.com Unabridged". In: (2017). URL: http://www.dictionary.com/browse/augmented-reality.

[6] J. D. Finn. "School Engagement and Students at Risk". In: *National Center for Education Statistics* (1993). URL: https://nces.ed.gov/pubs93/93470a.pdf.

[7] Matthew Hallberg. *Augmented Reality Tutorial: APPLE ARkit is AMAZING!!!* 2017. URL: https://www.youtube.com/watch?v=S7kKQZuOdlk.

[8] Hannes Kaufmann. *Collaborative augmented reality in education*. 2003. URL: http://netgened2011.flatclassroomproject.wikispaces.net/file/view/10.1.1.12.2215\%5B1\%5D.pdf/218089936/10.1.1.12.2215\%5B1\%5D.pdf.

[9] K. Kiili and H. Ketamo. "Evaluating Cognitive and Affective Outcomes of a Digital Game-Based Math Test". In: *IEEE Transactions on Learning Technologies* PP.99 (2016). URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7886272.

[10] Helen M. Marks. "Student Engagement in Instructional Activity: Patterns in the Elementary, Middle, and High School Years". In: *American Educational Research Journal* 37.1 (2000), pp. 153–184. URL: www.jstor.org/stable/1163475.

[11] Patrick O'Shea et al. "Lessons Learned About Designing Augmented Realities". In: *Int'l Journal of Gaming and Computer-Mediated Simulations* (2009), p. 15. URL: https://pdfs.semanticscholar.org/6cde/77becd373273bb096e5f7b40543b6b8b8266.pdf.

[12] Jason Tanz. *Apple Bets the Future of Augmented Reality Will Be on Your Phone*. 2017. URL: https://www.wired.com/story/arkit-augmented-reality/.

[13] Unity Technologies. *Unity ARKit Plugin*. 2017. URL: https://www.assetstore.unity3d.com/en/#!/content/92515.

[14] M. Templeman. *Virtual and Augmented Reality Marketing Strategies for the Coming Decade*. 2017. URL: https://foxtailmarketing.com/virtual-augmented-reality-marketing-strategies-coming-decade/.