

The Use of Information and Communications Technologies in High School Physics Classrooms

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Chapter 1: Introduction

In the past few decades, there have been many major scientific and technological breakthroughs. One of the most important of these breakthroughs is the computer. Computers have become almost ubiquitous. Every field and industry utilize computers in some form or another, and the education field is no exception. Many schools have recognized that computers have irreversibly become part of the day-to-day life of their students, and instead of condemning this change, have moved to embrace it. Indeed, computers have become one of the most relied upon tools for modern day students and educators. Some districts have even taken the step of giving every student in the district their own personal device for school related use. These so-called one-to-one districts have fully embraced the power of the computer as a learning tool, rather than a distraction.

With the introduction of computers as tools for learning has also come a variety of online and digital tools for use in learning. Some of these tools, such as the game *Kahoot!* can be applied to any content area as long as the teacher knows how to apply it. Other tools, such as *Physics Education Technology* (PhET), are targeted to a specific content area, in this case, science. Regardless of which content area a learning tool has been developed for, if any, the fact remains that these tools all have something in common. The fact that these tools

have been designed for the dissemination and discussion of information have led to them being dubbed as information and communication technologies, an umbrella term that covers any digital program designed for the dissemination of information. Information and communication technologies are extremely useful in the classroom and present a myriad of options and tools that science teachers can use to enrich their teaching. Information and communication technologies can increase student performance in the classroom, student motivation in learning, and can even help students more easily learn complex and abstract topics (Poultsakis, Papadakis, & Kalogiannakis, 2021). It is no surprise then that information and communication technologies provide an enticing tool for science teachers, whose classes are often seen as difficult, boring, and overly abstract. Therefore, this literature review will delve into the uses of information and communication technologies specifically through the lens of their uses in science classrooms.

Of the many, many types of information and communication technologies available, there are three that appear most useful in the context of science education. The first of these is augmented reality, a tool that allows for the demonstration of three-dimensional ideas in relation to a real life environment. The second is digital simulations, a tool that allows for demonstration of ideas that are abstract and hard to visualize, or dangerous and inconvenient for classroom demonstration. They also allow for experimentation with this kind of idea without the need for complex or, in some

cases, impossible setups in the classroom. Finally, the third form of information and communications technology that appears most useful in science classrooms is video games. Of these three categories, video games may be the most useful in every content area, as they are incredibly versatile and almost always a hit with students.

Chapter 2: Literature Review

Augmented and Virtual Reality

Many people have heard the term virtual reality. In fact these days, it often gets thrown around without stopping to think about what it actually means. Many people consider virtual reality to be the stuff of science fiction, but it indeed exists today. Virtual reality is the idea of replacing one's physical environment with a completely digital one, which allows for complete immersion with the new environment. Often this is done through the use of technologically complex headsets or other devices, which allow for the isolation of the user's senses. As fascinating as this technology is, the truth is, it is rather difficult to use in many applications, due to the fact that it requires expensive tools for use and completely cuts off a user from his or her physical environment. If only there was a way to combine the best aspects of both physical and virtual reality in one technology (Önal & Önal, 2021).

Enter augmented reality. Augmented reality is a rather recent innovation that, as stated before, combines the best aspects of both virtual and physical

realities into one technology. Augmented reality works by creating a digital overlay onto physical reality, essentially projecting digital constructs into the real world. This is often done with the use of a camera. One of the most commonly known uses of augmented reality in day-to-day life is the popular mobile game *Pokémon GO*, which allows the user to find and capture collectible monsters in the real world using a camera (Nielsen, Brandt, & Swensen, 2016).

Augmented reality has a variety of uses in the classroom. It can allow students to interact with virtual models of various objects, such as stars, that are impossible to interact with in everyday life. It can also create digital representations of things on top of physical objects, such as a virtual representation of human body systems on top of an actual human body (Nielsen, Brandt, & Swensen, 2016). Finally, it allows for visual demonstrations of complex and abstract topics, giving students a level of familiarity with otherwise difficult to visualize topics (Önal & Önal, 2021).

In 2016, Nielsen, Brandt, and Swensen conducted a research project to determine how experts feel about the use of augmented reality in the classroom. For the purpose of their research, Nielsen, Brandt, and Swensen defined an expert as a person in one of three categories. The first category was currently active teachers at the secondary level with six or more years of experience. The second category was presently active researchers in the field of science education. The third category of expertise was expert information and

communications technology designers. Nielsen, Brandt, and Swensen polled three members from each of these categories in each of four participating countries, Denmark, the United Kingdom, Spain, and Norway. This resulted in a total of 35 participants in the study, as only two information and communications technology designers could be found in Norway (Nielsen, Brandt, & Swensen, 2016).

Each of these experts participated in a two-round survey. The first round of the survey consisted of questions asking participants to list what they think some of the benefits and pitfalls are of using augmented reality in the classroom. The second round consisted of asking the experts their opinions on some of the answers to the first round of the survey. In this way, the researchers attempted to reach a level of consensus among the opinions of the participants (Nielsen, Brandt, & Swensen, 2016).

Overall, Nielsen, Brandt, & Swensen found that most experts had positive opinions toward the use of augmented reality in the classroom. Many participants cited interactivity as one of the best parts of the technology, fifteen percent of participants mentioned it in some way. Others liked the fact that it could add content to the surrounding area for the students, increasing the relevance of the content that was being taught (Nielsen, Brandt, & Swensen, 2016).

Experts also listed some of the pitfalls they could think of regarding augmented reality. One of the major pitfalls that was mentioned was the technology barrier. Augmented reality relies on the use of some sophisticated and expensive equipment that is not always available for every potential user. One of the other mentioned concerns was that augmented reality may not actually add anything useful to the lessons that isn't already there. Some experts were concerned that it would become more of a gimmick than an actual tool (Nielsen, Brandt, & Swensen, 2016).

In 2021, Önal and Önal conducted research on the effectiveness of the use of augmented reality in an astronomy classroom. The study was a traditional study that consisted of splitting the sample group into an experimental group and a control group. In this case, the sample consisted of 51 students in the seventh grade from the central region of Turkey. Students were also described as being gifted in the area of science, with the potential of becoming scientific professionals in the future (Önal & Önal, 2021).

The experimental group in this study consisted of 25 of the aforementioned 51 students. They were exposed to an augmented reality tool developed specifically for use in this study. The lesson the students were taught consisted of the Solar System. The control group was not exposed to the augmented reality tool and was instead taught the lesson in the traditional manner (Önal & Önal, 2021).

The data collection consisted of a pre-test and a post-test, along with a Likert scale survey on student interest in astronomy and a survey to determine student responses to the use of augmented reality in their class. Both groups were exposed to the same pre and post-tests and the student astronomy interest survey was used to determine whether or not student prior interest had a skewing effect on the research. It was found that prior interest did not have a significant effect on student performance in either group. It was also found that the experimental group, which was exposed the augmented reality tool, significantly outperformed the control group on the post-test, indicating that the use of augmented reality in the class helped improve student performance. Also, student responses to the use of augmented reality was overwhelmingly positive, indicating that not only does augmented reality improve student performance, but it also makes science learning more enjoyable to the students, a strong argument in favor of the use of augmented reality in science classrooms (Önal & Önal, 2021).

Digital Simulations

One of the most useful tools in the science classroom is the simulation. Some concepts are impossible to physically demonstrate and experiment with in the classroom. Some phenomena are too dangerous. For example, nuclear physics and chemistry are wildly risky to even be near, let alone to demonstrate in a high school classroom. Some concepts are simply too abstract to

demonstrate, like the idea of chemical reactions or orbital motion. These things both occur on a scale that is impossible to observe, one is simply too small to be seen, and the other is several orders of magnitude too large. Digital simulations can recreate these phenomena on scale that is convenient and interactive for students. Finally, some ideas require expensive or hard to come by equipment to demonstrate, such as certain physics experiments that require specialized equipment. A digital simulation can recreate the phenomena that these expensive tools are used to observe and demonstrate at a fraction of the cost. However, opponents of using digital simulations in the classroom argue that using this kind of information and communications technology can reduce the effectiveness of experiments in the classroom by removing the real-life aspect of the experiment. This, they argue, makes experimentation in the classroom less effective because it removes the relevancy of the experimental process.

Studies have been done on the effectiveness of the use of simulations in the classroom. In 2021, Chinaka performed a research trial to determine the effectiveness of using simulations compared to phenomenon-based learning in South Africa. The purpose of this research was to determine the effectiveness of simulations on the learning of a particular physics topic, two-dimensional motion. Two-dimensional motion presents an effective area for research on simulation-based learning because it is a heavily abstract topic that is easily visualized on a computer (Chinaka, 2021).

The research was performed using 154 students in South Africa ranging in ages from 18 to 24 years. The study group was split into four groups, two experimental groups and two control groups. One experimental group and one control group were given a pre-test, the other two groups were not. Then, the experimental groups were taught a lesson on two-dimensional motion using a Physics Education Technology simulation. Finally, all four groups were given a post-test. Then, two weeks after the initial research was performed, three students from each group, a total of twelve, were interviewed on their experiences. The purpose of giving the pre-test to only half of the groups was to determine if exposure to the pre-test had a significant effect on the post-test scores of the students. It was found that it did not (Chinaka, 2021).

The results of the research showed that for this particular topic, two-dimensional motion, that the experimental groups statistically outperformed the control groups on the post tests. This means that for this particular topic, the digital simulations were more effective in encouraging student learning than the phenomenon based learning the control groups were exposed to (Chinaka, 2021).

The post research interviews were used to determine if the simulation had an effect on conceptual understanding of the topic of two-dimensional motion. Using a coding scheme, Chinaka analyzed student responses to the interview questions to evaluate student conceptual understanding. The results indicated

that the experimental groups also had a more solid conceptual grasp of the concept compared to the controls groups. Overall, this research is a very strong argument in favor of using simulation-based learning in science classrooms (Chinaka, 2021).

In 2023, Banda conducted a similar study in Malawi, a small country in eastern Africa. The study consisted of 280 students of high school age. 155 were male and 125 were female. Banda used a standard experimental design to determine this relationship, meaning there was one experimental group and one control group. The experimental group was exposed to a Physics Education Technology simulation during a standard physics lesson. The control group was not exposed to this simulation (Banda, 2023).

The students were also given pre and post-tests. The results of the study showed that the experimental group statistically outperformed the control group, meaning the simulation was effective in student learning. Banda also used a statistical tool to determine if the method used was the reason for the student performance, or if it was the students themselves. His findings indicated that it was the method used, not the students, that caused the improved performance of the experimental group (Banda, 2023).

The problem with Banda's research is that Malawi is one of the poorest countries in the world. Many schools in Malawi do not have reliable access to computers or computer-based learning. This means that the improved

performance shown by the experimental group could have been due to student desire to use the computers, a rare event for them. Therefore, it should be considered that the poor state of Malawi and the rare access to computers could have caused the improved performance, whereas in a country where computers are more easily accessed and therefore less remarkable, this phenomenon may not occur (Banda, 2023).

Again, similar research on this topic was conducted by Yunzal and Casinillo in 2020. Yunzal and Casinillo sought to determine the relationship between student achievement and engagement and the use of simulations in the classroom (Yunzal & Casinillo, 2020).

Yunzal and Casinillo conducted their research in the usual fashion, separating their sample into two groups, an experimental group and a control group. The sample consisted of seventy-two grade twelve students in the Philippines. Both groups were administered a pre-test and then the control group was taught about the topic in a lecture-based fashion while the experimental group was taught about the topic through the use of a Physics Education Technology (PhET) simulation. The topic of the lesson was electrostatics, the study of the behaviors of charged objects (Yunzal & Casinillo, 2020).

Overall, the research results indicated that using a simulation instead of a lecture-based approach has a mild positive effect on both student

engagement and student performance in the classroom. However, there are some flaws with this research paper. Little is stated about what the researchers did with the data gathered from the pre-test. There is no indication that the researchers used this data to determine relatively equal ability levels in the two groups. There is also little evidence to support the claim that the students were more engaged with the simulation, which is troubling. It is possible that this evidence exists, but very little of it was reported in the research, which is somewhat troubling. Overall, Yunzal and Casanillo's results should be taken with a grain of salt as there is enough evidence there to create a suspicion of unreliability (Yunzal & Casanillo, 2020).

Research was also conducted by M. G. Saudelli and his or her partners on the efficacy of simulations in the physics classroom. Saudelli wanted to determine if using simulations had a more positive effect on student learning than a traditional, lecture-based teaching style. To do this, Saudelli referenced notes taken by a professor at a Canadian university. This professor was in the process from changing over from a lecture-based teaching style to one that included simulations from Physics Education Technology. This research was conducted on a group of eighty students at this university (Saudelli et al, 2021).

There were other data gathering tools as well. Data gathering tools included the professor's lesson plans, observations made by the professor's

colleagues, and an anonymous survey that was administered to the students that took part in the research (Saudelli et al, 2021).

Many of the comments made by the professor in his notes indicated a positive opinion of the use of simulations. The professor noticed increased student involvement and engagement with the material, a sentiment that was echoed by some of the survey responses. One student stated that the simulations were a “Fun and interactive way to make learning Physics more of a visual experience, which really helped me get it” (Saudelli et al, 2021).

However, the professor also had some misgivings about using the simulations. They indicated that the simulation seemed to encourage a more “passive” style of learning, which could have a negative effect on student outcomes in the future. Another concern was the fact that not all of the simulations had the same effectiveness. It was observed that some of the simulations served more as a demonstration of the phenomenon in question, rather than an interactive experience, which limited student ability to really engage with the topics. These kinds of simulations did not have as positive of an impact as the other, more interactive ones did (Saudelli et al, 2021).

One question that may emerge from the discussion of simulated experiments is whether or not they are better than actual, physical experiments at encouraging student learning. A paper by F. Ajredini and company sought to answer this question (Ajredini et al, 2014).

To answer this question, Ajredini conducted research on two-hundred twenty-five students in the tenth grade in the Republic of North Macedonia, a small Balkan state located just north of Greece. Ajredini separated the sample into three groups, consisting of eighty-six, eight-one, and fifty-eight students, respectively. The first group was exposed to a lesson consisting of an actual, physical experiment. The second group was exposed to a lesson consisting of a digitally simulated experiment. The third and final group was exposed to a lecture-based lesson with no experiment. Each group was administered a pre-test and a post-test to collect data on student performance after the lessons were administered. (Ajredini et al, 2014).

The final results of the experiment indicated that there was little difference in student understanding between physical experiments and digitally simulated experiments. At first, one could interpret this as indicating that digitally simulated experiments have no use, as they provide no benefit over physical experiments. However, it is equally valid to say that this could mean digital experiments are just as valid of a learning tool as physical experiments. Digitally simulated experiments are cheaper and less time consuming to set up, and also allow for a broader variety of experiments to be conducted in the classroom (Ajredini et al, 2014).

However, this experiment has some drawbacks. Firstly, the researchers chose to analyze only one multiple-part question on the pre-tests and post-tests.

This seems like a bad idea, as now they only have data on how students perform on a single question, rather than on student understanding of the topic as a whole, which a more comprehensive analysis would provide. The researchers also did not compare the two experimental groups, the groups exposed to the physical and digitally simulated experiments, to the control group, the lecture only group. This seems like a massive oversight. The researchers have no evidence now over whether or not experiments in the classroom are useful at all. It also smells of sloppy experimental design, as there was no point in including a lecture only group if there was no intention to use the data gathered from that group. More accurate data could have been gathered from the other two groups had the experimental group been simply divided between them (Ajredini et al, 2014).

There has also been research conducted into the opinions of actual science teacher on whether or not to use digital simulations in science classrooms. Poultsakis and two other researchers conducted a broad survey on this topic in 2021. The research consisted of the researchers administering a survey to one-hundred seventy-six teachers in Greece. The survey consisted of ninety-eight questions. Some were simple yes or no questions, some were Likert style questions on a five-point scale, and some were extended response questions (Poultsakis et al, 2021).

The results of the survey indicated a few things. Firstly, it indicated that the vast majority of teachers in the sample used digital simulations some of the time or more in their classrooms. This indicates that digital simulations are a popular tool among teachers and this should be taken as a general endorsement of the tool as a learning tool (Poultsakis et al, 2021).

Surprisingly, Poultsakis' research also indicated that the age of the teacher in question had very little to do with whether or not the teacher actually used digital simulations in the classroom, as one might expect. In fact, there were two main factors that might have caused teachers to not use this tool in their classrooms. The first was the availability of the necessary technology. Poorer districts tend to not have as consistent access to the computers necessary to use this kind of tool, and that can cause teachers to avoid using them regularly. Secondly, teachers that have not been trained to use this kind of tool are much less likely to use them, as they tend to be less confident in their abilities to use the tools properly (Poultsakis et al, 2021).

Video Games and Gamification

Video games are the third area of information and communications technology that will be explored in this literature review. Video games are quickly becoming one of the most prominent pastimes among high school aged students. Therefore, it is a foregone conclusion that using video games in the classroom helps with student motivation. Indeed, research supports this

claim. Video games are an important tool for educators because they have built in motivation in the form of achievements and rewards, which encourage the players to succeed at the game. Therefore, if a game is educational and relevant to the topics in question, it helps encourage students to want to learn in the classroom.

Video games, and games in general, have emerged in the classroom scene because of a process called gamification. Gamification is the process of integrating game like elements in non-game environments. Gamification has become extremely popular in business fields and has recently become a popular topic in educational areas as well. A lot of research has been done in the field of gamification in classroom environments in the past few years.

Yesiltas and Cevher decided to do some research into this topic in 2021. They decided to analyze the trends and ideas that have been increasingly permeating modern educational research. Yesiltas and Cevher used a digital method of scanning and analyzing the keywords and citations of a large number of articles in a single research database. Using this information, they were able to look at the trends for different areas of research in the database (Yesiltas & Cevher, 2021).

To do this, Yesiltas and Cevher chose to use the Web of Science database, which is a product of the Thomas Reuters Institute for Scientific Information. According to the article, this database hosts over thirty-seven

thousand different journals and over one-hundred seventy-one million individual pieces of literature. This large amount of literature makes this database a convenient tool for analyzing trends in educational research, as it provides a significant cross section of the existing body of literature. This database was chosen for conveniences sake because it also allows for easy searching and sorting based on bibliographic information. (Yesiltas & Cevher, 2021).

To search the database, the keyword “digital games” was searched for in the document titles, keywords, and abstracts of every article in the database. This returned seven-hundred sixty individual articles for analysis (Yesiltas & Cevher, 2021).

The results analyzed used a bibliometric analysis technique. The results were sorted in various ways in order to provide a look at the many variables involved in the different articles. Firstly, the articles were sorted in a manner indicating the number of articles published in each year of the study. For the year range of 2005 to 2017, there was a general increase in the number of articles published. There was a significant outlier with a large number of articles published in 2007, which Yeşiltaş and Cevher hypothesize may have been due to the increased use of the internet in the early 2000's. There were many other categories that the articles were analyzed by. The vast majority of articles were written in English, the majority of publications were scholarly articles or

proceedings papers, and the vast majority of papers were published from institutions in Taiwan or the United States. (Yeşiltaş & Cevher, 2022).

The article also analyzed the number of times each paper has been cited and then sorted the number of citations made every year. Interestingly enough, a graph of number of citations made versus the year of citation makes an almost perfect graph of an exponential function. This indicates that the interest in digital games in education has increased greatly through the years (Yeşiltaş & Cevher, 2022).

Shute, Ventura, and Kim decided in 2013 to research whether or not these games had a positive impact on student learning, as before applying this tool to many classrooms, there should be significant research done into its effectiveness (Shute et al, 2013).

Shute used a standard experimental design, splitting the sample group into an experimental group and a control group. The sample consisted of one-hundred sixty-seven students in eight and ninth grades at the Florida State University School. The game that was used in this research project was a tool called *Newton's Playground*. *Newton's Playground* is a game that was developed in order to develop student understanding of Newtonian physics through the use of simple machines. The goal of the game was to move one ball to another ball by using various simple machines. The motivating factor was medals awarded to the students upon successfully completing a level, with higher value medals awarded if students used less tools to move the ball.

Additionally, a prize of 25 dollars was awarded to the student with the most success in the game. (Shute et al, 2013).

Students were also administered a qualitative pre and post-test before and after playing the game, respectively. Students were also administered a Likert Scale survey on how much they enjoyed the game and how much they play video games in general in their personal lives. (Shute et al, 2013).

The results showed a statistically significant increase in student performance on the pre/post-test after playing the game. The researchers also attempted to figure out if high engagement in the game resulted in higher performance on the post test. Researchers tallied the number of levels attempted by each student and used this as an indicator of engagement, with more levels attempted indicating higher engagement. They found that higher engagement students, students that attempted more levels, had higher amounts of improvement on the post test. (Shute et al, 2013).

Video games are often seen as a more male oriented hobby. Therefore, the researchers decided it would be pertinent to test for any variance due to gender in the results. They found that not only does gender not determine student enjoyment of the game, but that students of different genders also have similar learning outcomes after playing the games, which means that gender did not play a significant part in the results determined by the experiment. (Shute et al, 2013).

In 2013, Anderson and Barnett conducted a similar experiment. This article explored the impact of the use of a game as the basis of a physics unit in five middle school classes. Specifically, the unit in question was electrostatics, the study of electric charge and its effect on other objects, and the game in question was a game developed by the Massachusetts Institute of Technology called *Supercharged!* A control group was created with two classes consisting of 32 students, the three remaining classes were used as the experimental group, consisting of 59 students. The school in question is located in the northeastern United States. While the experimental group used *Supercharged!* as the basis for its learning experience, the control group used a series of guided inquiry experiences. Both groups were expected to learn the same content. (Anderson & Barnett, 2013).

Both qualitative and quantitative data were recorded for this research. Students were administered a 12-question pre-test. Random subsets of each group were also independently interviewed in order to determine student understandings of certain concepts. After the experiment was administered, students once again took the test and were administered interview questions. Classes were also recorded on five video cameras in order to capture relevant moments in the classes. One camera focused on the teacher, a second camera was moved around the classroom, and the remaining three cameras were focused on the students playing the game. Likewise, two researchers were in the room recording observations at all times. (Anderson & Barnett, 2013).

The results show that the game had a small but statistically significant effect on student success in the understanding of electrostatics. Students in the experimental group on average outperformed students in the control group. The researchers also tested to see if gender had a statistically significant effect. They found that it had no effect on the experimental group, but also found that males outperformed females in the control group. (Anderson & Barnett, 2013).

Qualitatively, both groups demonstrated little understanding of electrostatics before the experiment. Afterwards, however, it was shown that students in the experimental group were able to recall experiences from using *Supercharged!* to answer conceptual questions. The paper indicates that students in the control group depended more on memorization of certain facts to answer interview questions. (Anderson & Barnett, 2013).

Overall, this cross section of research indicates that information and communications technology can be an extremely powerful tool, not only for improving student achievement, but also for improving student engagement and student motivation.

The literature indicates that simulations almost always have a positive effect on student learning. Simple visuals and interactivity allow for digital simulations to have great effects on students.

Games and augmented reality also seem to have positive impacts on student engagement and achievement. However, the body of research that exists on these two categories is much smaller than that for simulations. This

could be due to the fact that these two technologies have not existed for as long as digital simulations have. However, regardless of the size of the body of research, the literature that does exist indicates that these too can be used as powerful tools for student learning.

Chapter 3: Research

Given that the majority of the research in the literature review focused more on the academic side of information and communications technology and how it impacts student achievement, it would be safe to assume that it is a useful tool that educators should know how to implement in the classroom. However, there is a stunning lack of literature on exactly how to implement information and communications technology in the classroom. The goal of this paper is then to determine fifteen information and communications technology tools in the three categories specified in the literature review and implement them during lessons in an actual physics and astronomy classroom to determine how to best use these tools in the future.

Methodology

The goal of this research paper is to determine fifteen information and communications technology tools that could be useful in a physics and astronomy classroom. A further goal is to implement them into a lesson in an actual physics and astronomy classroom. The third and final goal is to determine if the implementation during the lesson was successful. If not, it will be

determined why the lesson was unsuccessful and to brainstorm ways to better implement the tool in future lessons.

Data gathering techniques will be as follows. First, a list of information and communications technology tools that would be useful in the physics and astronomy classroom will be created. Second, lessons will be developed, one for each tool, that will integrate the information and communications technology tools into the physics or astronomy curriculum. For individual lesson plans, please see appendix A. The instructor will observe student responses to each information and communications technology tool to see if the implementation of that tool is successful in the lesson. Instructor notes for each lesson will be included in appendix B. Finally, teacher notes will be analyzed to determine if the implementation of the specified tool was successful. If not, the notes will be further analyzed to determine why the first implementation was unsuccessful, and, based on instructor notes, determine how the lesson could be modified or changed to more successfully implement the information and communications technology tool.

The Tools

First, the tools were determined. Each tool fits into one of the three categories covered in the literature review. The three categories are games, simulations, and augmented reality. Surprisingly, the hardest tools to find were those in the games category, of which only four tools were determined to be useful. The reason for this is twofold. First, there was a lot of overlap between

games and simulations. Universe Sandbox was first determined to be in the games category, but was later determined to be a better fit for the simulations category. Second, it was determined that there was a lack of games not necessarily in physics and astronomy, but a lack of games in physics and astronomy that would be *useful in the classroom*, an important qualifier. For example, the video games series *Mass Effect* has a lot to do with astronomy, and many science fiction properties do, but it is not useful in the classroom, as the astronomy and physics aspects of the game are not the focus.

In the end, most of the tools were determined to be in the simulations category. Overall, there were four tools in the games category, seven tools in the simulations category, and four tools in the augmented reality category.

The Study

This study took place in a high school physics and astronomy classroom. Students ranged in age from fifteen to eighteen. The three physics classes consisted of a total of fifty-three students, thirteen females and forty males. In addition, nine of the students are classified as students with disabilities. For the astronomy class, there were a total of nineteen students, four female and fifteen males. Five of them are classified as students with disabilities.

The physics classes are taught to the New York State Regents standards. Therefore, lessons were designed with those standards in mind. The astronomy class was taught with respect to the Next Generation Science Standards.

Games

The three games that were investigated were as Kerbal Space Program, Phys 1, Phys 2, and Kahoot. Universe Sandbox could also be considered a game, but it was decided that it fits more into the category of simulations rather than games. For each of these four games, a lesson was developed and implemented in a classroom. The instructor of that class proceeded to observe student response to the implementation of the tool and take notes accordingly. For more in-depth details on individual tools, please see appendix A. For a quantitative representation of observations, please see appendix B.

Kerbal Space Program

A Popular Learning Tool

Kerbal Space Program is a spaceflight simulation video game that features realistic orbital mechanics. In the game, the player creates and manages a spaceflight organization staffed by green-skinned humanoids called Kerbals. Kerbal space program's primary advantage is looking at how orbital mechanics work in real life, and its orbital mechanics engine is extremely sophisticated. It allows players to perform real life orbital maneuvers with their custom designed spacecraft. Some goals of the game include putting a spacecraft in orbit, putting a Kerbal on the Mun (the game's equivalent to Earth's moon), and eventually, visiting other planets.

Kerbal Space Program's engine is extremely sophisticated, allowing for real life orbital maneuvers to be performed in game. The game tutorial starts small, allowing a user to put a small craft into orbit, and then guides the user

through how to change the shape and size of that orbit by changing the craft's velocity. Eventually, using the lessons taught by the game, the goal is to put an astronaut on the Moon. This takes practice, and oftentimes, players will fail several times before successfully making a moon landing. At that point, the game becomes very much a sandbox, allowing the used more freedom to complete their goals as they see fit.

Kerbal Space Program's advanced orbital mechanics engine allows for very in-depth study of two things in the astronomy classroom, Kepler's Laws of Orbital Motion, and spaceflight. Kepler's Laws can be understood by completing the orbit tutorial at the beginning of the game and the complexities of spaceflight can be understood by simply playing the game, giving players a realistic understanding of the difficulty of reliably achieving space missions in real life.

Unfortunately, due to its complexity, Kerbal Space Program has proved to not be a particularly useful tool in the astronomy classroom observed in this study. Students in this study were given the goal of putting a Kerbal on the moon, and then playing with the game however they saw fit after that point. Four of the higher achieving students in the class were able to complete this goal, while most of the other students had a much harder time of it. Some of the students were completely unable to even put a ship into orbit around the starting planet.

Kerbal Space Program was introduced as part of the spaceflight unit in the astronomy class. The lesson consisted of two forty-four-minute periods during which students were tasked with landing a craft in the game on the Mun.

For Kerbal Space Program, the teacher notes were mixed. Of the thirty-five observations, twenty of them, or fifty-five percent of the observations made by the teacher during instruction, were positive. Particular notes were made that the students really seemed to enjoy doing something different for class than a traditional lecture or project. Of the remaining nine observations, eleven of them indicated that the students had some level of confusion on how to attain the expected goal of reaching the Mun or difficulty understanding the academic language used in the game. The last four observations noted by the teacher indicate that some of the students were completely unengaged with the lesson. One student put her head down and would not participate despite requests to do so. Other students became distracted upon multiple failures or difficulty playing the game.

Unfortunately, due to its complexity, Kerbal Space Program has proved to not be a particularly useful tool in the astronomy classroom observed in this study. Students in this study were given the goal of putting a Kerbal on the moon, and then playing with the game however they saw fit after that point. Four of the higher achieving students in the class were able to complete this goal, while most of the other students had a much harder time of it. Some of the

students were completely unable to even put a ship into orbit around the starting planet.

Phys 1

A Game for New Physics Students

The Phys games are applications that were designed for cell phones and computers with the intention of teaching users about physics. Phys 1 focuses primarily on kinematics, that is, objects in motion. It provides problems regarding an object's position, velocity, and acceleration. Phys 1 was introduced in the physics classes as part of the kinematics unit. It was introduced as an alternative to practice problems regarding objects moving in a straight line. Students were given time to complete a set number of problems in the game as an assignment grade for the class. The lesson lasted for one forty-four-minute class period.

In this classroom, Phys 1 was introduced as part of the second unit, one-dimensional motion, as a tool for practice solving problems. The game allows users to measure various quantities and use them in their calculations, and then apply those calculated values to a simulation to see if they work correctly. Students seemed to enjoy using the app. Most reported that the app was challenging, but not too difficult to solve.

Students responded fairly positively to Phys 1 as a learning tool for kinematics. One student was quoted as saying "I like doing this better than

worksheets", to which the surrounding students were noted as agreeing. Of the observations made, thirteen of the twenty-one, sixty-two percent were positive. Some of the students were noted as complaining specifically about the content, but not the app itself, which was three of the twenty-one observations, and then the remaining five were complaints about how the app worked. Some students were noted as complaining about how well the app ran on their laptops, stating that it was lagging or stuttering, and some just complained about the app not working right.

Phys 1, students reported, had some issues with measurement values not being exact enough. As a result, students could get a problem wrong even when presenting a correct answer. Phys 2 does not have this issue, but it is also less dynamic and visually engaging than Phys 1.

The biggest problem with these applications is that they are no longer available on any app stores. They are also android specific. As a result, the only way to play the games is to download them on a Microsoft, Apple, or Google device onto their laptops. Therefore, if the plan is to implement these tools in the classroom, teachers should be advised that the technological tools need to be installed on their students' computers ahead of time.

Phys 2

A Better Game from the Same Company

Phys 2 was implemented much in the same way as Phys 1, except as part of the two forces units in the physics classes. The first forces unit focused on objects in equilibrium and so students were assigned levels in the game that focused on those particular problems. As the lessons proceeded from equilibrium to non-equilibrium, more levels were assigned to give students practice with the new topics, including friction and circular motion. Overall, Phys 2 was used for four forty-four-minute class periods, one for static forces, one for dynamic forces, one for friction forces, and one for centripetal forces.

The Phys 2 app was introduced as part of Unit 3, forces, as a way to explore the concept of net force. Students reported that this app was less enjoyable than the first, because it lacked the animations that the first game had, but also reported that it worked better. From a teaching perspective, Phys 2 seems like a more consistent learning tool, as it is much easier to obtain the correct values. However, there are no measurement features in Phys 2, which is where most of the difficulty arose in Phys 1.

Over the course of the four class periods, sixty observations were recorded by the teacher. Of the sixty, forty-five of them indicated a positive view of using the Phys 2 software. This accounts for seventy-five percent of total observations over the four class periods. In addition to the forty-five observations indicating a positive response to the software, forty of them, with some overlap, indicated that the students were highly engaged with the program. Several students were noted as competing with each other to see who could get the best score on

the assigned levels of the game. This indicates that the Phys 2 software is a highly engaging and positive learning tool.

Unfortunately, just like Phys 1, Phys 2 is not available on any app stores. However, both applications are available on the Microsoft store for PC's, which makes it installable on many devices in 1:1 school districts.

Kahoot!

A Well-Known Review Tool

Kahoot is a website that allows for many players to play a single game. Each game consists of a number of questions that students can answer. The way the game is played is usually like this; the teacher will project the game on the board and students will log into the lobby on their phones or laptops. Students will then answer questions from those same devices. The game keeps track of students' scores in real time and displays the rankings in between each question.

Kahoot actually proved to be the most popular of the four games. For this lesson, a Kahoot session was created for review of an astronomy class unit before the unit exam was administered. The topic of the unit was stars. For the lesson, students were expected to participate in the Kahoot in order to review for the test the next day.

Kahoot has experience a boom in recent years as a teaching tool. Usually, teachers will implement Kahoot in their classrooms as review tools. It is an extremely convenient tool because it is completely customizable on the part of

the teachers, although some question types are locked behind a subscription. However, teachers can write their own questions, create their own quizzes, and also post their quizzes publicly for others to use. Students often respond well to Kahoot review sessions.

Overall, almost every note taken for the Kahoot lesson was positive. Of the twenty observations that were made, only three of them were negative. Students were observed being fond of the competition aspect of Kahoot along with being able to see the placements of each student after each round. Students were, however, observed creating inappropriate names for themselves in the game or complaining about lack of connectivity. A couple of students created usernames and then proceeded to not actually participate in the Kahoot session. Overall, however, students responded very positively to the Kahoot and also performed particularly well on the test the next day.

Simulations

There were seven tools that were classified as being included in the simulations category. These were Gizmos, Physics Education Technology (PhET), Universe Sandbox, Physics-Lab, Physlet, OPhysics, and Orbiter. Much like the games category, students were administered a lesson that involved the implementation of one of these simulation tools. Unlike the games category, where the lessons usually focused around playing the game as an assignment, the simulations lessons were administered with some form of guided worksheet, which walked the students through using the simulation to answer various

questions about the phenomenon. These worksheets were then graded and used to analyze student performance.

Gizmos

A High-Quality Simulation Software

Gizmos are an educational tool created by ExploreLearning, an online resource dedicated to creating tools to help educators in science, technology, engineering, and math (STEM) fields. ExploreLearning also creates other tools, such as Reflex, Frax, and Science4Us. These tools are focused, however, on younger age groups and are not the focus of this section, which is Gizmos.

Gizmos is a tool that consists of online simulations meant to help convey abstract and difficult to demonstrate ideas in a manner that is accessible, interesting, and fun.

In the classroom in this study, several Gizmos tools have been used to demonstrate various phenomena in a safe and educational setting. Phenomena studied using Gizmos in this classroom include Coulomb's Law and the photoelectric effect on the physics side of the classroom, eclipses and the tides in astronomy. Students in this classroom who have used Gizmos to learn new topics have shown an excellent understanding of those topics, regardless of prior exposure to that topic. Students also showed excellent responses to using Gizmos as review tools or as extra practice for topics that have already

been covered in class. One student was noted as saying “I like Gizmos. They explain things in a way I understand.”

Part of this positive response to using Gizmos can be attributed to the exploration guides. Each simulation comes with a walkthrough that explains the phenomena represented in the simulation with several guiding questions that help students reach scientific conclusions.

One should not use Gizmos without prior diligence, however, as they often use vocabulary that students may not understand. Several students were noted as not understanding the term “eccentricity” in the Gizmo simulation on the Kepler’s Laws of planetary motion, a term that had not yet been covered in class.

Gizmos are useful in a variety of science disciplines. All four of the regent’s sciences are represented, physics, chemistry, biology, and Earth science. There are also some topics represented that are not included in regent’s curricula, such as astronomy and botany. That being said, there are certain topics within the main sciences that are not represented. For example, the Standard Model of particle physics has no represented simulations, even though it is a major component of the modern physics unit in regent’s physics. Another example of a missing topic is the theory of relativity, another major physics topic. And one that would really benefit from a simulation detailing how it works.

Of the tools used in this study, Gizmos were used most prominently, because they were already integrated into the existing physics curriculum of the classroom in question. Over the course of the study, several Gizmos were used across the physics and astronomy classes, so one Gizmo was selected for actual observation. This was the Kepler's Laws Gizmo that was implemented in the astronomy class. The Gizmo presents a simulation of a planet orbiting a star, and allows the user to change the planet's velocity and acceleration vectors to change the path of its orbit. The Gizmo also comes with a student exploration packet that was handed out to the students. They were instructed to use two forty-four-minute class periods to complete the student exploration packet. The packet directed the students to use the simulation and take observations that allow them to observationally determine Kepler's Three Laws of Planetary Motion.

Over the course of the two class periods, twenty observations were taken. Twelve of them indicate a positive view of Gizmos as a class tool. The remaining eight reflect a feeling of tedium and repetitiveness that accompanies Gizmo simulations. Students were noted as being put out because they found Gizmos to be repetitive because the student exploration packets require them to take multiple of the same observations and do multiples of the same calculations. Some students indicated that they were tired of Gizmos because they have used them in other classes, so there may be some level of negative association with the tool from prior use.

Overall, the students respond mostly positively to using Gizmos in the classroom. Rarely do students fail to answer questions correctly because the student exploration handouts give the students the tools necessary to answer the questions for themselves, rather than guessing or asking someone else. When asked what they like about Gizmos, one student responded by saying, "I like that it shows me what the correct answer is." When asked what they meant, they responded "Instead of just telling me why something is, it shows me why that has to be the case. It backs up what it tries to say." From this we can gather that some students prefer being shown where certain physics facts come from, rather than just being told. One student said they didn't like Gizmos because "They are too repetitive" because some data gathering questions ask them to do the same calculation repeatedly, which is a valid complaint. Sometimes they do this to illustrate a certain point, but it can be tedious to do it over and over.

PhET

Simulations from University of Colorado

Physics Education Technology, commonly abbreviated as PhET, is a series of simulations created in 2002 specifically for physics education at the University of Colorado Boulder by 2001 Nobel Physics Laureate Carl Wieman. Physics education technology originally started specifically for physics classes, but has since branched out into all science disciplines and also mathematics.

In the classroom specified in this study, Physics Education Technology has been primarily used for teaching students mathematical techniques that are necessary in physics classrooms. This is because Gizmos does not have simulations that focus specifically on mathematics, so physics education technology is another great option.

The biggest problem with implementing Physics Education Technology in the classroom is the lack of guiding activities to go along with the simulations. Unlike Gizmos, which often have guiding activity to help students understand the phenomenon being simulated, Physics Education Technology usually does not. This is likely because Physics Education Technology is not for profit, so there are not people being paid to actively create content for them. This means that any educators that want to use Physics Education Technology in the classroom have to create any companion activities to the simulations themselves. While this gives teachers greater freedom to create the activities they want, it also creates more work for the teacher as there is no convenient activity ready-made for them to use.

Out of the seven tools used in the simulations category, Physics Education Technology (PhET) may be the most well-known. PhET is a project created at The University of Colorado Boulder in 2002 with the express goal of reaching as many students as possible with easy-to-understand physics education.

When implemented in the classroom in question, a guiding activity was also created that the students were asked to use the simulation to work through. Students were being taught how to add vectors together graphically, so the Physics Education Technology vector addition simulation was being used. This simulation allows students to graphically add vectors in both one and two dimensions, and also allows them to create a graphical representation of the sum of those vectors. This proved extremely helpful for a couple of reasons. Firstly, it is much faster and more efficient than drawing vectors by hand. While hand-drawing vectors is a perfectly acceptable method of adding them, it introduces an element of human error to the situation. This brings us to the second main advantage of using the simulation, and that is the fact that it computes the resultant vector itself, again removing the possibility of student error through misunderstanding.

Overall, students responded very positively to this lesson. Students had been given prior instruction on vector addition and it seemed as though they still lacked a concrete understanding of the topic. When they were asked if the simulation helped them with their understanding of vector addition, most of them responded in the affirmative. Of the thirty-two observations made during instruction, twenty-nine of them, about ninety-one percent. Of the remaining three, some students indicated that they were still struggling with understanding vector addition and stated that the simulation did not really help with increasing their understanding of the topic.

Universe Sandbox

A High-Quality Space Simulator

Universe Sandbox could have been included in the games category, but it was decided that the functionality of the software makes it a better fit for the simulations category instead. Universe Sandbox is a simulation style program developed by video game developer *Giant Army*. Universe Sandbox is exactly what it sounds like, a large-scale simulation of astronomical objects, giving the player/user free reign to change anything about the objects in the simulation. This allows students that are using the simulation to accurately observe the effects that changing certain variables has on these astronomical objects.

One example of a phenomenon that can be observed in Universe Sandbox is the birth of a star. Starting in a simulation of the Solar System, users can increase the amount of hydrogen present on a planet. If that hydrogen level increases beyond a certain amount, the gravitational force created by the planet in the simulation will force the hydrogen to undergo nuclear fusion, turning the planet into a star. This allows students to observe how increasing the fuel supply in a small area would allow for the creation of a new celestial object.

Universe Sandbox is extremely useful in astronomy classes, where the observation of a star and its behavior is a large topic of conversation. But there are other things that Universe Sandbox allows its user to do as well. Universe

Sandbox can allow students to alter an objects velocity and acceleration vectors, effectively changing the objects orbital trajectory.

Overall, Universe Sandbox is effective because it allows its user to observe various "What If?" scenarios, allowing for vast potential to study and understand phenomena that are not normally observable or demonstrable in the classroom.

Universe Sandbox really increased student engagement in the classroom in this study. The game is well designed, allowing for beautiful three-dimensional renderings of the astronomical phenomena in question. Students really seemed to enjoy using the software, with many of them remarking that it was fun to use and watch objects crash into each other, or to make a star transform into a black hole.

Of the twenty-two students in the class, none of them had anything bad to say about the software. Many of them praised how good the animations looked, while others wondered what else they could do with the software. Some students did indicate that they had some difficulty understanding how to start, but were easily shown how to work through the software with the instructor's assistance. Overall, this software was very popular with students and kept them very engaged with the lesson. This corresponds to twenty-one observations, eighteen positive, three negative.

With that being said, there are a few large problems with using Universe Sandbox in the classroom. Firstly, it is fairly resource intensive for computers to

run, so many schools will be unable to implement it without upgrading hardware. The user interface can also be confusing for first time users, so a guide to how to use the software would be helpful, or a step-by-step walkthrough detailing how students can make various phenomena occur.

Universe Sandbox's greatest strength is also its greatest weakness. Universe Sandbox allows the user a large amount of freedom to engage in various activities, but this can be overwhelming for many students. Some students in the class in question had a hard time staying on task when using Universe Sandbox. This makes it a great tool for engaging with various phenomena, but as a tool for studying them, there are likely better options.

In the classroom in this study, many of the students really enjoyed using Universe Sandbox. The students enjoyed exploring the different options the simulation had to offer. One student said it was "really cool" when he turned a star into a black hole by increasing its mass. Another student was noted as watching what would happen if Mars' orbit was moved to collide with Earth. Interestingly, the vast majority of the students, when given free reign, played with black holes more than anything else.

Physics-Lab

Phone Application for Physics Experiments

Physics-Lab is an application that allows for the simulation of a few different kinds of physics scenarios. Namely, Physics-Lab allows for the user to

perform experiments with astrophysics, circuits, and electromagnetism. The primary use of this application when implemented in the classroom was the electromagnetism section. This is because the astrophysics section is very similar to Universe Sandbox, which has already been discussed, and Universe Sandbox is better in practically every aspect. The circuits section works well, but the classroom in question already has everything necessary to perform circuit experiments in real life, and therefore this section of the application is unnecessary. However, if a classroom were to implement the circuits section of the application because they did not have the required materials for circuit experiments, this app would work well.

When implemented in the classroom, this application was primarily used for its electromagnetic simulation potential. This app allows the user to create virtual positive and negative charges, shows them what the electric field around that charge would look like, and allows them to place test charges to determine how a charge would move in that particular electric field. It also allows the user to do the same thing with magnets and magnetic fields. The students were instructed to use the electromagnetism part of the app to place various charge sources to see how different test charges would move in that scenario. They were then instructed to do the same thing with various magnetic field sources to see how a compass would behave in the given magnetic field.

Overall, this application received mixed reactions from students. Of the forty observations made of the physics students, twenty-two were generally

positive. Most of the students liked the fact that the application actually showed them what the various field lines would look like for a given source. Some of them also liked the fact that they got to use their phones for the lesson. However, the phone aspect also proved to be somewhat of a distraction as some of the students were noted as using their phones but not using the application as directed. Some of the students also complained of still not understanding magnetic fields as well as they would like.

Physlet

Old School Physics Simulations

Physlet is a series of physics simulations created specifically for physics education. Using Physlets in the classroom is extremely easy due to the fact that every simulation comes with a series of practice questions designed to further understanding of the phenomenon associated with the simulation. For this lesson, the Physlet simulation that was used was based on Snell's Law and total internal reflection and also the simulation on diffraction. Students were given the link to the simulation and then told to answer the questions that went along with the simulation. For the Snell's Law simulation there were four questions and for the diffraction simulation there were three.

This tool also had mixed reactions from the students. Of the thirty-eight observations made during this lesson, nineteen were positive and nineteen were negative. Some students liked the visual representations of the different phenomena and also liked the fact that the simulations allowed them to

change different aspects. However, some students complained of unclear instructions due to formatting issues on the website, and some were noted as not being aware of the functionality of some aspects of the simulation. For example, some students did not know that the angle could be changed on the Snell's Law simulation.

Physlet is implementable in a variety of physics lessons. Topics include mechanics, fluids, waves, thermodynamics, electromagnetism, circuits, and optics. This is extremely convenient, as many of those topics are covered in high school physics classrooms.

Most of the students demonstrated working understanding of Snell's Law after using the Physlet simulation, with 45 out of 52 students demonstrating a good understanding of the phenomenon on the practice questions. Students also seemed to have more difficulty understanding diffraction, with only 39 out of 52 students scoring demonstrating a good understanding. This seems to be due to the fact that refraction (Snell's Law) is a phenomenon that students can encounter in real life and are familiar with, while diffraction is less easy to identify in real life.

oPhysics

Physics Simulations by a Physics Teacher

OPhysics is a website that hosts a variety of physics simulations, created by veteran physics teacher Tom Walsh. OPhysics is a useful tool to walk students

through a variety of physics simulations ranging a large number of topics. This tool was implemented in the physics class during two lessons in the electrostatics unit. Students were assigned the Millikan Oil Drop simulation and the Electron Charge to Mass Ratio simulation. These are two simulations that together allow students to determine the charge and mass of an electron. Students were given a packet that walked them through how to perform these experiments to determine these two values.

Student reactions to these two simulations were mixed. Although most students seemed to understand the ideas behind the experiments, several students were noted as being less than engaged. Some of them complained that the simulations were hard to use and some of them indicated that the simulations were boring because they were fairly stark and uninteresting looking. Overall, of the 41 observations made by the instructor, sixteen of them were negative, while nineteen of them were positive. The remaining six could not be easily sorted into those two categories.

Students showed decent understanding of both experiments, with the Oil Drop experiment being more well understood by most students. 40 out of the 52 students showed understanding of the Oil Drop experiment, while 38 out of the 52 showed good understanding of the Cathode Ray Tube experiment. This discrepancy is likely due to the fact that the Cathode Ray Tube experiment includes a magnetic force, while the Oil Drop experiment does not. This class has

shown a level of difficulty understanding force due to magnetic fields on charged particles.

Overall, OPhysics seems like a good resource for physics teachers. Since it was designed by a physics teacher, it includes things that physics teachers will often need. However, the user interface is somewhat bland, which a number of students complained about, but the sheer variety of available simulations makes it a resource that should not be ignored.

Orbiter

Flight Simulator in Space

Orbiter is a spaceflight simulator similar to Microsoft Flight Simulator. It has 3-dimensionally rendered environments and allows its user to execute realistic spaceflight maneuvers on various planets and astronomical bodies.

One of the most intriguing aspects of Orbiter is the fact that it includes various real-life spacecraft, such as the module from Apollo 11, that users can use to emulate real space missions.

When implemented in the classroom, students were instructed to try to complete the Apollo 11 mission as a class project. Students responded very positively to this implementation, many of them seemed to enjoy crashing the spacecraft more than actually completing the project. However, it provided an excellent insight to the complexities and intricacies of true spaceflight.

Overall, this piece of software shares a lot of issues with Kerbal Space Program. Students indicated that it was hard to use and understand, although many of them seemed to be having fun flying around the solar system. This tool was implemented during a lesson as part of the spaceflight unit in the astronomy class. Of the nineteen observations made, fifteen of them were positive, mostly praising how fun the game was or how engaged the students were with the software. Three of the remaining four were complaints about the difficulty of using the software and the last observation was of one student who was completely disengaged from the lesson and had her head down for the entirety of the lesson.

Augmented Reality

There were four tools discovered that fell into the augmented reality category. They were measurement apps, Microsoft Math Solver, Solar System AR, and Star Tracker. Unlike the other categories of tools that were often the focus of their own lessons, augmented reality tools were used more as supplements to other lessons. As a result, they were more easily placed into existing lessons, rather than having new lessons designed around them.

Measurement Apps

Good in Theory, Results Lacking

Measurement apps are a type of augmented reality technology that allow for a user to measure objects simply using the camera on their phone. Utilizing trigonometry, a phone camera is able to determine the distance from

an object, and from there can use various angles to measure lengths and distances. These apps can also utilize various units of measure, including both metric and imperial, making them flexible enough for a variety of applications.

In this classroom, students were tasked with using this app to measure the lengths of various objects during a lab. However, problems quickly arose with the app not properly or accurately measuring objects. The problems arose with the app being unable to properly use the camera to determine the distance from an object. Several groups reported that the app was not returning accurate values when compared to physical measuring tools. Several measurements returned values that were off by over 100%. Therefore, initial attempts to implement this technology in the classroom were not successful.

During the course of the observations, it became immediately obvious that this type of technology does not function as well as it could. It consistently returned incorrect values or failed to recognize the surface that was being measured. Of the 38 observations made using this tool, almost all of them were negative. One student was noted as saying she wished it worked better because the idea seemed useful. Another downside was noted that many of the measurement applications available for use on cell phones require some sort of in-application purchase or subscription to be usable.

However, there are other areas that this technology can be used in the classroom other than its intended purpose of measuring the lengths of objects.

Because of the app's frequent failure to return proper values for measurements, it can be a useful tool in discussing error in experiments. By discussing reasons for why the app is returning inaccurate values, it becomes easier to discuss where error in measurements comes from with other tools as well.

The app is also useful for discussing the different conversion factors for different units of measure. Because the app is able to measure lengths in different units of measure, it becomes possible to utilize the app to discuss how units can be converted into different units. Conversion factors are the numbers the you can multiply one unit by to change it into a different unit. In previous years, unit conversions have been a point of failure for many students, even converting between metric units, which are only factors of ten. Therefore, any technology that can improve student understanding of this topic can be useful in the classroom, even if the tool itself is not successful in its initial goal.

Solar System AR

Interesting Concept Ruined by Advertisements

Solar System AR is an application that is available for smart phones that displays three-dimensional renderings of the planets and other astronomical bodies in virtual space using the user's camera. This technology was implemented in a lesson as part of the astronomy class's solar system unit in which they investigated the properties of the various objects in the solar system.

Students were given a worksheet and asked to answer questions on the various planets.

This app was implemented in an astronomy classroom during the unit on the solar system, which covered the eight planets, the sun, asteroid and Kuiper belts, the Oort Cloud, and the dwarf planets. This application was implemented during the section of the unit that focused on the eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune). This application was used as a tool for the students to walk through the solar system's various objects and learn more about them after they had been discussed in class. After the class used the application, they came back together and discussed what they had learned as a group.

This technology was not particularly well received by the students. Of the twenty observations made during the class, only two were positive. One student thought the renderings of the objects looked cool and another thought that the application provided interesting information. However, this is overshadowed by two major complaints. Two of the students complained that the app did not actually do anything, just displayed a picture and some writing. So, the lack of interactivity was a failing point. But the remaining sixteen observations were students complaining about the advertisements on the application. In order to unlock new objects to look at in the application, users are forced to watch an advertisement. This was a major complaint about this application.

The largest complaint about the app, however, was the limited selection of objects that the application provided for the user. There are twelve objects available for the user to view in the application, the eight planets, the Sun, the Moon, and Pluto. Since the students had already covered the solar system in class, they knew that there were various other objects that the app could have shown them, such as the dwarf planets, comets, and asteroids. This left them feeling as though the app had limited their ability to learn using it. Students were also annoyed by the fact that the app only allows the user to view Earth and the Moon at first, and required them to watch an advertisement to unlock another planet to look at.

Overall, the app provides some interesting information via its descriptions of the planets, but its major limitations left a lot to be desired from the students. If this application were to be implemented in another classroom, one should use it as either an introduction to the planets, or as a study tool.

Microsoft Math Solver

Powerful Tool but Easily Abused

Microsoft Math Solver is a really useful augmented reality tool that can be used for a variety of mathematical purposes. Developed by Microsoft, it is an application that can scan for various mathematical problems and solve them. Problems can be typed or handwritten. By taking a picture of the problem, Microsoft Math Solver then solves it, and also provides step-by-step instructions

on how to solve the problem. It also includes an impressive array of mathematical features, being able to do arithmetic, algebra, calculus, linear algebra, discrete math, and graphing. The application also includes a feature that allows the user to write problems by hand into the application and it will solve them from there as well.

Forty-five observations were made of this tool's use in class. Thirty of them, making sixty-seven percent of the observations, were positive, with students using the app mostly to check their work or seeing what they could and couldn't do with it. The remaining fifteen observations were of students using the app to bypass having to do work in class. These students were reminded to use the app properly or its use would be banned in the classroom. Overall, this application seems useful but easily abused in the classroom.

There are two things that are intriguing about this application in the physics and astronomy classroom. The first thing it can be used for is teaching students how to set up equations. This is what was done when implemented in the study classroom. Students were provided with a kinematics problem in physics class. They were also given the solution to the problem. They were told to set up their equation and then use Microsoft Math Solver to solve what they had written. If the application returns the same answer as the provided answer, this means that the students set up their equation correctly. The application can also walk them through how to solve their equation to get that answer.

When implemented in the physics classroom, it became immediately apparent that this was a useful tool. There are several students in the classroom in question due to various disabilities with math. By using this application to teach them how to set up their equations, they are showing much more confidence with their equation solving. Whereas in previous weeks, they have been coming up to the instructor and asking if they have been setting up their problem correctly, they are now showing more confidence in setting up their equations, and second guessing themselves less often.

The second thing that has become immediately apparent upon using this application in the classroom is its potential for accessibility. Many students with learning disabilities struggle with implementing mathematics. This application provides a lot of potential for helping students like that in the classroom. Once students have shown that they are able to set up equations properly, this application can then walk them through how to solve the problems step-by-step. Students with difficulties in math can then follow those steps, and through this method, can then become more practiced in correctly solving math problems.

There are some problems with this application, however. Firstly, it is missing the ability to implement some mathematical operations. Although the examples are fairly limited, one of the major examples was the modulo operation, which is a mathematical operation used to find the remainder of a division problem.

Another concern with implementing this application is the worry that students will use it to solve their problems for them but not use it to learn the problems. The application is not meant to be a crutch, but rather a tool that students can eventually wean themselves off because they no longer need help. Finally, there is little in the way of scaffolding within the app. Even though it can walk students through how to solve a problem, if students fail to understand those steps, then there is little in the app that can explain how those steps are actually implemented.

Star Tracker

Augmented Reality Tool for Night Sky Watching

The last augmented reality tool that was investigated was the Star Tracker application. StarTracker is an application that shows its user an augmented reality generated overlay of the night sky. By pointing the device camera in different directions, the application displays what astronomical objects are visible to the user in that direction.

This app was implemented early on during the school year in an astronomy classroom during the class's discussion on the night sky and astronomical coordinate systems. The class had discussed altitude-azimuth coordinates, right ascension-declination coordinates, and constellation-based coordinates. The application was introduced as a tool for students to use when observing various night sky objects. Students were asked to go home and

wait until dark, then use the app to observe the night sky to see what objects they could find.

The application displays various night sky objects that are visible from Earth. The most prominently noticeable feature is the constellation tracker, that will display an outline of whatever constellations that camera happens to be pointed at during use. If the user looks a little bit closer, however, one can begin to see other objects as well. The application also displays the names of various stars in the constellations. One student reported finding the star Polaris when using the application, which is visible all year in the northern hemisphere. The student in questions was then able to use the application to verify the technique that had been covered in class by using the stars in the Big Dipper to verify Polaris's location.

Some of the students took to this immediately. Four of the students immediately downloaded the application and started using it in the classroom, which was great for stimulating discussion amongst the students. Some of the students, however, were completely disengaged from the lesson. One student was noted as putting her head down for a large portion of the class, while two more were observed having an off-topic conversation during the unit. Overall, however, this application seemed to be very engaging for the students. Of the nineteen observations made, sixteen of them were positive.

The application displays various night sky objects that are visible from Earth. The most prominently noticeable feature is the constellation tracker, that will display an outline of whatever constellations that camera happens to be pointed at during use. If the user looks a little bit closer, however, one can begin to see other objects as well. The application also displays the names of various stars in the constellations. One student reported finding the star Polaris when using the application, which is visible all year in the northern hemisphere. The student in question was then able to use the application to verify the technique that had been covered in class by using the stars in the Big Dipper to verify Polaris's location.

The application also shows various deep sky objects, such as the galaxy Andromeda, which had not yet been discussed in class. The student in question was surprised to find out that other galaxies are visible from Earth and that they look a lot like stars to us!

Another student pointed out that they had seen Jupiter, which was visible in the night sky during that time of year. Again, this student showed surprise that the planets were visible from Earth, and also questioned why they glowed and looked like stars, which was able to be tied back into the class's discussion of the moon reflecting the light of the sun.

Some students also questioned why the app still displayed stars and objects during the day. It was then explained to them that certain stars are only

visible during certain times of the year, and when they appear in the same part of the sky as the sun, they can't be seen. StarTracker is not limited by this because it uses coordinates and augmented reality technology to create its display, not just its camera.

Overall, the class responded extremely positively to this application. Several students indicated their interest in going back out on other nights to use the app again, outside of class requirements. At least one student still had the app on his phone at the end of the semester and was still actively using it.

Results

Overall, the most useful tools for this type of technology were determined to be the simulation style tools. These that students, on average, responded most positively to, and they also seemed to have the greatest positive effect on student engagement.

The least popular category of tools were the augmented reality tools, which seemed to have the issue of not being particularly ready for use in some situation. An overabundance of advertisements and poorly created tools really hampered the students' responses to this kind of tool. There definitely were tools that the students enjoyed using, but only a couple out of the four had a positive impact on student engagement.

Finally, the game style tools mostly were positively received by students as well. Games have a long-standing positive reputation in classrooms and digitizing them has done nothing to diminish this positive quality.

Chapter 4: Conclusions

As we have seen in the last two chapter, there is a surprising dearth of academic literature regarding the implementation of specific information and communication and technologies in the classroom, science or otherwise. This paper will serve to document the implementation of several information and communication technologies in a high school physics and astronomy classroom. Care will be taken to provide information on all three potential areas of information and communication technologies covered in the previous chapters of this paper, augmented reality, simulations, and video games. Each section of this chapter will cover a specific information and communication technologies tool and document the implementation techniques used, the findings and notes of the researcher regarding the tool in question, and any future questions that could be answered with future research.

The fifteen information and communications technology tools discussed in this chapter each provide unique and interesting opportunities for instruction in physics and astronomy classrooms. Each of them was used and implemented in a physics or astronomy class, so each of these has been investigated for implementation opportunities in a real classroom. Overall, each of these can be recommended as useful tools in real classrooms.

Games

Out of the three categories of information and communications technology tools, games proved to be the most popular amongst the students. This is not unexpected, due to the built-in competitiveness of the various game tools. However, this does not mean that they are the most effective type of information and communications technology tools of all. Game based information and communications technology tools can be excellent engagement tools, but sometimes they can become a distraction in the classroom if they are not used properly. Sometimes the students become more concerned with playing the games than they are with actually learning the content that the games are based on. Regardless of this, games are an effective tool for increasing student engagement in the classroom.

Simulations

Simulations are certainly the most widely available information and communications technology tool for physics and astronomy classes. They are an excellent tool for this kind of class because they allow for students to observe things that they otherwise would be unable to observe. However, this does not mean that they should be used as a replacement for actual experiments. Simulations are useful because they allow for student to observe the otherwise unobservable, but research also shows that actual, in-person experiments are more conducive to student learning than simulations are. Regardless, physics

and astronomy often discuss topics that would otherwise be unable to be observed, meaning that simulations are extremely useful in these content areas and for teachers that teach these topics.

Augmented Reality

Augmented reality is a promising technology for teachers, especially when used by instructors that understand the complexities and the subtleties of the technology. However, commercially available augmented reality tools for physics and astronomy education are still fairly hit or miss. Educators should not, however, dismiss this technology as a whole. New tools for this technology are being created and improved every day, and there are existing tools that do work. This does mean, though, that educators who plan to use this technology and these tools should be extremely selective when choosing which ones to use.

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Appendix A: ICT Tools

Title:	Kerbal Space Program
Source:	Developed by Squad Published by Private Division
Regents Standards:	HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
Resources/Supplies:	Kerbal Space Program, students will need a laptop or other device.
Key Topics:	Spceflight, Orbits
Rationale:	Orbital behavior is a complex topic, one that students will experience a marketed improvement in if they are able to see actual representations of orbital motion and astrodynamical behavior in real time
Description:	Kerbal Space program is a sophisticated real time simulator of spaceflight and orbital dynamics
Reason for choosing:	Orbital motion and astrodynamics are an important part of any space based class and Kerbal Space Program is one of the best and most powerful simulators of that kind of motion
Potential Misconceptions:	KSP can be hard to understand. Recommend a handout with step-by-step instructions on how to use before implementing in class. Recommend using multiple class periods to implement.
Implementation Recommendations:	Use multiple class periods Use a handout to explain how to use
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Phys 1
Source:	Osmosis Games
Regents Standards:	HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system
Resources/Supplies:	Phys 1, students will need a laptop with Microsoft
Key Topics:	Kinematics
Rationale:	Kinematics is a topic that requires a lot of repetitive practice, this program allows that practice to be a little more fun
Description:	An application that has users solve kinematics problems in order to complete levels
Reason for choosing:	Kinematics is an important part of any introductory physics program and makes up a full unit in the regents curriculum
Potential Misconceptions:	Phys 1 can sometimes return results that are slightly off from what they should be
Implementation Recommendations:	Use as practice for new physics topics, assign students given problems in for practice
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Phys 2
Source:	Osmosis Games
Regents Standards:	HS-PS2-1. Analyze data to support the claim that Newton's Second Law of Motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
Resources/Supplies:	Phys 2, laptop that runs Microsoft
Key Topics:	Forces, Equilibrium, Friction
Rationale:	Forces is a difficult topic that requires a lot of practice to develop a skillset in, this app allows for a fun, easy to use software for practice in this topic
Description:	An application that has users solve force problems in order to complete levels
Reason for choosing:	Forces make up the largest portion of any introductory physics curriculum and is often considered by regents students to be the hardest part of the entire class;
Potential Misconceptions:	Students have the potential to reach new topics before they are introduced in class
Implementation Recommendations:	Use as a practice tool for forces, make sure students know when to stop so that they do not move ahead into new topics too early
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Kahoot!
Source:	Kahoot! ASA kahoot.com
Regents Standards:	Used as a review tool, therefore does not need to conform to content standards
Resources/Supplies:	Device capable of accessing internet
Key Topics:	Spceflight, Orbits
Rationale:	Physics is a complex topic that requires a lot of review in order for a student to be successful. Kahoot allows for this review to take place in a fun, gamified environment.
Description:	A tool that allows students to answer instructor created questions in a competitive, gamified manner
Reason for choosing:	Review in physics and astronomy can be boring and tedious unless implemented in a correct manner, any way to increase student engagement with review material is a useful tool
Potential Misconceptions:	Unless students are paying attention, they may answer incorrectly without realizing it
Implementation Recommendations:	Use as a review tool, best used with memorized content, such as vocabulary
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Gizmos
Source:	Explore Learning gizmos.explorelearning.com
Regents Standards:	Various
Resources/Supplies:	Laptop or computer capable of accessing the internet
Key Topics:	Various
Rationale:	Physics and astronomy often involves complicated topics that cannot be directly observed, so simulations can allow for students to observe these behaviors in visually engaging way
Description:	A series of digital simulations on various topics that come with guided inquiry packets and follow up questions
Reason for choosing:	The ability to have unobservable phenomena become visible to students is very powerful, especially for visual learners
Potential Misconceptions:	Gizmos can sometimes word things strangely, sometimes Gizmos approximate certain things for the sake of making a point
Implementation Recommendations:	Use the guided inquiry packets, make sure students understand the instructions
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Physics Education Technology (PhET)
Source:	University of Colorado Boulder phet.colorado.edu
Regents Standards:	Various
Resources/Supplies:	Laptop or computer capable of accessing the internet
Key Topics:	Various
Rationale:	Physics and astronomy often involve complicated topics that cannot be directly observed, so simulations can allow for students to observe these behaviors in visually engaging way
Description:	A series of digital simulations on various topics
Reason for choosing:	The ability to have unobservable phenomena become visible to students is very powerful, especially for visual learners
Potential Misconceptions:	PhETs can sometimes word things strangely, sometimes PhETs approximate certain things for the sake of making a point
Implementation Recommendations:	Create a guided inquiry packets, make sure students understand the instructions
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Universe Sandbox
Source:	Giant Army
Regents Standards:	HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
Resources/Supplies:	Universe Sandbox, laptop or other computer
Key Topics:	Orbits, Solar System
Rationale:	Space is a fascinating topic for many students and a visually engaging tool that allows them to create their own "What If?" scenarios is very engaging
Description:	A powerful gravity and astrodynamics simulator
Reason for choosing:	Allows students to create visual representations of their own ideas and run them in a realistic and visually engaging sandbox
Potential Misconceptions:	Universe Sandbox can use approximations for certain phenomena
Implementation Recommendations:	Use as an engagements tool, present students with various what if scenarios to run and answers questions on
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Physics-Lab
Source:	Turtle Sim LLC
Regents Standards:	HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
Resources/Supplies:	Phone with Physics-Lab installed.
Key Topics:	Electric fields, magnetic fields, electrostatic forces
Rationale:	Electric and magnetic fields are often difficult for students to visualize, so this presents them with those topics in a visual medium
Description:	Simulation tool that allows students to experiment with circuits, electrostatic, and astronomy
Reason for choosing:	Electrostatics is difficult to visualize without help. However, there are better circuits and astronomy simulators
Potential Misconceptions:	Does not often display the interactions between charged particles and magnetic field properly
Implementation Recommendations:	Use as inquiry based tool to learn about electric and magnetic field and forces
Accessibility Recommendations:	Students with orthopedic impairments may have difficulty using, recommend pairing with a partner

Title:	Physlet
Source:	Developed by Wolfgang Christian and Mario Belloni compadre.org/physlets/
Regents Standards:	Various
Resources/Supplies:	Laptop or other computer capable of accessing internet
Key Topics:	Various
Rationale:	Physics and astronomy often involve complicated topics that cannot be directly observed, so simulations can allow for students to observe these behaviors in visually engaging way
Description:	A series of digital simulations on various topics
Reason for choosing:	The ability to have unobservable phenomena become visible to students is very powerful, especially for visual learners
Potential Misconceptions:	Physlet can sometimes be somewhat obtuse with its functionality
Implementation Recommendations:	Make sure students know how to use simulation, utilize questions that come with the simulation
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	OPhysics
Source:	Developed by Tom Walsh ophysics.com
Regents Standards:	Various
Resources/Supplies:	Laptop or other device capable of accessing the internet
Key Topics:	various
Rationale:	Studying famous experiments allows students to learn how real physicists conducted their research
Description:	A series of physics simulations created by a physics teacher for the express purpose of being used for physics education
Reason for choosing:	Some famous experiments are hard to replicate in the traditional physics classroom for various reasons. This provides the next best option for experiencing these experiments in real life
Potential Misconceptions:	Make sure students understand the exact functionality of the simulations
Implementation Recommendations:	Create a guided inquiry assignment to walk students through how to use the simulations
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Orbiter
Source:	Developed by Martin Schweiger orbit.medphys.acl.ac.uk
Regents Standards:	HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
Resources/Supplies:	Laptop or other computer with Orbiter installed
Key Topics:	Spceflight, Orbits
Rationale:	Orbital behavior is a complex topic, one that students will experience a marketed improvement in if they are able to see actual representations of orbital motion and astrodynamical behavior in real time
Description:	Orbiter program is a sophisticated real time simulator of spaceflight and orbital dynamics
Reason for choosing:	Orbital motion and astrodynamics are an important part of any space based class and Orbiter is a powerful simulator with functionality students may be familiar with
Potential Misconceptions:	Orbiter can be hard to understand. Recommend a handout with step-by-step instructions on how to use before implementing in class. Recommend using multiple class periods to implement.
Implementation Recommendations:	Use multiple class periods Use a handout to explain how to use
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Title:	Measurement Applications
Source:	Various Apps available on App Store
Regents Standards:	Obtaining, Evaluating, and Communicating Information
Resources/Supplies:	Phone or other device with a measurement application installed
Key Topics:	Units, measurement, uncertainty
Rationale:	Measurement and units are a fundamental part of all science classes, and having a firm understanding of them is an important part of being successful in any science classroom
Description:	Applications that use augmented reality to measure objects in reality
Reason for choosing:	Measurement and units are a fundamental part of all science classes, and having a firm understanding of them is an important part of being successful in any science classroom
Potential Misconceptions:	These applications are extremely finicky and often return values that are extremely inaccurate.
Implementation Recommendations:	Use as a tool to demonstrate systematic error and allow for practice with percent error calculations
Accessibility Recommendations:	Students with orthopedic impairments may have difficulty using, recommend pairing with a partner

Title:	Microsoft Math Solver
Source:	Microsoft
Regents Standards:	Obtaining, Evaluating, and Communicating Information.
Resources/Supplies:	Device with camera and Microsoft Math Solver installed
Key Topics:	Mathematics
Rationale:	Physics and astronomy are mathematically dense fields that often require large numbers of complicated calculations in order to be successful
Description:	An application that uses augmented reality to analyze and solve various math problems, including hand written
Reason for choosing:	Physics and astronomy are mathematically dense fields that often require large numbers of complicated calculations in order to be successful
Potential Misconceptions:	Students may think that this can take the place of actual math skills. Students may want to use this in place of actually solving their problems
Implementation Recommendations:	Use as a learning tool, make sure that students cannot use it as a crutch to do their work for them
Accessibility Recommendations:	Orthopedically impaired students may have difficulty writing formulae that the app can recognize due to writing difficulties. Recommend allowing access to a tool for typing equations

Title:	Solar System AR
Source:	Developed by Jeremy Zhang
Regents Standards:	HS-ESS1-1. Develop a model based on evidence to illustrate the life span of the Sun and the role of nuclear fusion in the Sun's core to release energy that eventually reaches Earth in the form of radiation.
Resources/Supplies:	Phone with Solar System AR installed
Key Topics:	Solar System
Rationale:	The solar system and the astronomical bodies within are an important part of an astronomy curriculum and this allows them to be visualized in an impressive manner
Description:	An application that creates augmented reality projections of various astronomical objects along with descriptions of them
Reason for choosing:	The solar system and the astronomical bodies within are an important part of an astronomy curriculum and this allows them to be visualized in an impressive manner
Potential Misconceptions:	Students may think that the app has additional functionality besides the immediately obvious. It does not
Implementation Recommendations:	Would not recommend using this, the advertisements are egregiously intrusive.
Accessibility Recommendations:	Would not recommend using this, the advertisements are egregiously intrusive.

Title:	Star Tracker
Source:	Developed by PYOPYO Studio
Regents Standards:	HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
Resources/Supplies:	Phone with Star Tracker installed
Key Topics:	Stellar coordinates, astronomy, constellations
Rationale:	Being able to recognize various astronomical bodies is an important part of observational astronomy
Description:	An application that uses augmented reality to analyze the night sky and provide information on astronomical bodies that are in the direction the camera is pointing
Reason for choosing:	Being able to recognize various astronomical bodies is an important part of observational astronomy
Potential Misconceptions:	The application shows bodies that may not be visible, such as objects that are on the other side of the Earth or are out during the day
Implementation Recommendations:	Use as a tool to explore observational astronomy and what can be seen with the naked eye
Accessibility Recommendations:	Some students, such as epileptic students, will be unable to use. Recommend guided inquiry experience instead.

Appendix B: Observation Data

Tool Name	Total Number of Observations	Number of Positive Observations	Number of Negative Observations	Percent Positive	Percent Negative
Gizmos	20	12	9	60%	40%
PhET	32	29	3	90.625%	9.375%
Kerbal Space Program	35	20	15	57.143%	42.857%
Phys 1	21	13	8	61.905%	38.095%
Phys 2	60	45	15	75%	25%
Kahoot!	20	17	3	85%	15%
Universe Sandbox	21	18	3	85.714%	14.286%
Physics-Lab	40	22	18	55%	45%
Physlet	38	19	19	50%	50%
oPhysics*	41	19	16	46.341%	39.024%
Orbiter	19	15	4	78.947%	21.053%
Measurement Applications	38	2	36	5.263%	94.737%
Solar System AR	20	2	18	10%	90%

Microsoft Math Solver	45	30	15	66.667%	33.333%
Star Tracker	19	16	3	84.211%	15.789%

*The remaining six observations of oPhysics could not easily be sorted into positive or negative