“Augmented Reality in Secondary Mathematics Classrooms”

An Honors Thesis

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Abstract

In this twenty-first century world, changes are occurring everywhere, including inside classrooms. The shifts in the field of education are not the result of the new technology, but rather the result of new learners with diverse needs (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014, p. 134). Overtime, Augmented Reality, or AR, has transformed from a futuristic tool into an innovative way to experience education like never before. AR has the capability of engaging all students, the "digital natives," within the classroom, converting them from passive members into active participants (Kiryakova, Angelova, & Yordanova, 2018, p. 557). By altering the perception of reality, students have opportunities to explore, manipulate, and interact with the course materials. This technological tool supplements and differentiates instruction by catering to the students' learning styles while also fostering concrete connections and deeper understanding (Bacca et al., 2014, p. 141; Antonioli, Blake, & Sparks, 2014, p. 97). Augmented Reality motivates teachers and students within the secondary mathematics classroom; although, this technology has potential for all ages and subjects. Classrooms no longer need to be stationary; learning can occur anywhere with the aid of Augmented Reality accessible at students' fingertips.

Keywords: augmented reality, secondary education, mathematics, differentiation

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Augmented Reality in Secondary Mathematics Education

Every day, technology becomes more prevalent and advanced in this ever-changing, twenty-first century world. It has changed the way that humans think and apply knowledge. As a direct result, there are new trends and applications in the field of education, including the use of Augmented Reality, or AR, in the classroom (Bacca et al., 2014, p. 134). Throughout recent years, Augmented Reality has transformed from a futuristic tool to an innovative way to experience learning like never before. This technology has the capability to enrich the delivery of instruction, increase engagement and motivation, promote differentiation, and become a powerful supplemental resource within secondary mathematics classrooms (Kiryakova et al., 2018, p. 557). Before implementing this technology, it is important to consider the uses, key features, and advantages as well as limitations of Augmented Reality in an educational setting.

Background

First, it is helpful to define Augmented Reality. AR is among the fastest growing technologies in recent years (Kiryakova et al., 2018, p. 556). This emergent technology lies in the middle of two extremes within the virtual continuum, which encompasses all of the ways in which humans can interact with a computer or device (Salinas, Quintero, Ramirez, & González, 2015, p. 3). AR fuses a computer-generated image on top of one's existing reality, the view of the real-world; thus, it alters the current perception of reality, enabling interactive and engaging features. Since Augmented Reality systems allow for "supplementing real-world objects with virtual objects or superimposed information," virtual objects appear to coexist in the same space as real-world items (Bacca et al., 2014, p. 133). Virtual objects can include text, still images, video clips, sounds, three-dimensional models, and animations (Bower, Howe, McCredie, Robinson, & Grover, 2014, p. 1). This system can be applied to many different, already existing technologies, such as computers, tablets, smartphones, and wearable devices, such as glasses (Antonioli et al., 2014, p. 96). Augmented Reality, however, differs from Virtual Reality. In a Virtual Reality system, the user is entirely immersed in a synthetic environment. In other words, Augmented Reality supplements reality, whereas Virtual Reality completely replaces it. Augmented Reality is not limited to sight, it can also be applied to other senses, such as sound and touch (Bacca et al., 2014, p. 133). It has the capability to blur previous boundaries.

There are many different types of Augmented Reality. First, Stationary Augmented Reality is a motionless system comprised of powerful cameras that accurately recognize objects from the real-world, whereas Desktop Augmented Reality uses a computer camera to identify objects from the reality and embeds virtual objects or content onto them. Next, Spatial Augmented Reality projects virtual content directly on real-world objects in actual sizes and proportions. There is Augmented Reality specifically designed for handheld devices, which uses GPS capabilities to establish the user's positions, while providing them with up-to-date information directly related to their location in the form of text, images, audio, and visual. Additionally, head-mounted displays are devices that combine the image of real and virtual objects in front of the users' eyes. Augmented Reality in contact lenses is still being developed to combine images of reality with embedded virtual content. Vision-based Augmented Reality typically occurs by using a camera to recognize markers, such as barcodes and QR codes. After analyzing the marker, the software produces virtual objects that are displayed on the screen and integrated with the real-world. There is a possibility that this AR style can be used without markers, where the software recognizes items, such as magazines, photographs, scenes, or faces, in order to distinguish them from the surrounding objects. Location-based Augmented Reality is a form of marker-less AR that uses GPS capabilities to determine the position of the device and provides information on objects and places near the user, which is identical to the handheld device features (Kiryakova et al., 2018, p. 560). These types of AR increase knowledge of the real-world by allowing users to access information about objects that is not available upon the glance from a naked eye.

Often times, students are now considered “digital natives,” but that truly depends on their access to the Internet and technology as well as the environment in which those tools are applied. However, there is an undeniable belief that the newer generations cannot be taught in the same traditional ways because the everyday use of digital devices impacts the way that young people perceive ideas, process information, and ultimately learn (Kiryakova et al., 2018, p. 557). Traditional methods consider learners as passive participants in the learning process; however, for the digital generation, that is an unacceptable position. For that reason, teachers need to adapt pedagogical approaches as well as implement new tools and technology throughout the learning process in order to encourage students to play an active role in the classroom (Kiryakova et al., 2018, p. 558). The engaging and interactive features of

AR, in comparison to other tools, naturally allow students to participate in the learning process and delve into the coursework.

Advantages

Physical objects and virtual information have been embedded in classrooms everywhere; however, until recently, the merging of those two worlds has been difficult. Augmented Reality offers the combination of the physical and virtual material, which draws on the strengths of both (Bujak, Radu, Catrambone, MacIntrye, Zheng, & Golubski, 2013, p. 1). With those strengths, "AR has the potential to change education to become more efficient in the same way that computers and the Internet have" (Antonioli et al., 2014, p. 96). Based on a literature review, which looked for patterns and trends in educational settings, there were many purposes of Augmented Reality in the classroom, which include deeper explanations and evaluations of topics as well as opportunities for laboratory experiments, educational games, and more. When using AR for research and exploration, students can interact in ways that are not always possible or safe in the real research process (Kiryakova et al., 2018, p. 561). In addition, Augmented Reality helps to reduce the cost of certain educational experiences over time while offering an inclusive opportunity for students with disabilities and distinct needs (Bacca et al., 2014, p. 140). For instance, teachers can overlay digital content on physical objects, which can help students with autism to manage their attention; an example of this style of AR is the Mobile Object Identification System (Salinas et al., 2015, p. 3). This method could also help the other students to stay on task by minimizing distractions.

Based on a collection of observations, other highly-noticeable advantages include learning gains, student and teacher motivation, interaction, collaboration, situated learning, student-centered experiences, exploration, innovation, positive attitudes, anticipation, authenticity, and novelty of the technology (Bacca et al., 2014, p. 141). Augmented Reality has the overall ability to bridge gaps and bring a more tangible approach to learning. For instance, student-centered activities can be enhanced by the incorporation of virtual and real-world experience, which can relate to the students' interests and life outside of the classroom walls. "An attractive, interesting, and fun learning environment is needed in order to keep students' attention on what happens in the class along with providing them with interactive, exciting, and unforgettable experiences that offer opportunities for active participation" (Kiryakova et al., 2018, p. 558). This is essential because it is the responsibility of educators to not only be knowledgeable about the content, but also be able to deliver that content in a safe, engaging environment that fosters learning and development.

Additionally, classrooms are filled with diverse students with unique needs. Teachers must be capable of differentiating and tailoring the lessons in order to meet the needs of the individual students. AR educational media helps to overcome the challenges of text-based methods by allowing students the opportunity to absorb material that aligns with their preferred learning style (Antonioli et al., 2014, p. 97). This technology has kinesthetic functions that many other instructional approaches do not include (Liou, Yang, Chen, & Tarng, 2017, p. 110). Students can choose how they want to interact with the content by selecting the way the materials are delivered, either through text, visuals, three-dimensional animations, or audio, in order to meet the students' needs and preferences (Kiryakova et al., 2018, p. 561). Augmented Reality experiences also provide an opportunity for interaction, communication, and the exchange of ideas and data in a variety of styles (Kiryakova et al., 2018, p. 557). Differentiating with AR is crucial because education is not a one size fits all scenario.

Learning Theories

Not only do students have the chance to explore the world in an interactive way, but Augmented Reality also encourages students to work collaboratively, which links to theories of constructivism. Constructivism encourages the teacher to become a facilitator, guiding the students to organize, synthesize, and analyze content. Augmented Reality allows this process to happen directly in the students' hands. AR allows students to work together in traditional school settings as well as globally. "The engagement of the student as well as their identity as a learner is formed by participating in collaborative groups and communities" (Antonioli et al., 2014, p.97). Furthermore, based on the constructivist learning theory, AR promotes deeper engagement in tasks, concepts, and resources in order to make lasting connections (Bower et al., 2014, p. 6). Augmented Reality also relates to the just-in-time learning theory, which suggests that the students learn information that they need to know now. In this ever-changing world, the students have readily available material at their fingertips, and the AR system makes the information accessible (Antonioli et al., 2014, p. 99). The material can be updated on demand (Salinas et al., 2015, p. 3). Students and teachers can view the world in a unique way as well as transfer knowledge and understanding immediately. Also, following the situated learning theory, the students can learn naturally through activities that are enhanced by manipulation, problem-solving techniques, simulation, and exploration within AR systems (Antonioli et al., 2014, p. 97). Situative theorists argue that the activities and contexts in which students learn are fundamental to what they learn (Estapa & Nadolny, 2015, p. 40). Authentic and contextualized learning embeds the real-world into educational environments (Bower et al., 2014, p. 6). Augmented Reality can also promote higher-ordering thinking within the Bloom's Taxonomy as students often demonstrate skills of application and analysis as well as creation. Also, further exploration increases student curiosity, which triggers questioning; therefore, AR reflects a natural inquiry-based learning style. Augmented Reality reflects another theory, the self-determination theory, because students learn through motivation (Antonioli et al., 2014, p. 97). The self-determination theory supports competence as students seek to control the outcome and experience mastery; relatedness as the individuals will interact and experience lasting connections; and autonomy as students work on their own growth and development (Estapa & Nadolny, 2015, p. 41). The intrinsic motivation to learn is increased because the students want to explore and seek out challenges naturally using the AR technology. The students who are engaged in meaningful activities are more likely to stay focused for longer periods of time and grasp more of the concepts (Antonioli et al., 2014, p. 97). AR fits all of these learning theories because it is flexible, and the technology can be compatible with the lessons in multiple ways. The way that the tool is implemented depends on the students that are in the classroom, which alters from year to year and from class period to class period.

Additionally, the cognitive information processing theory relates to Augmented Reality software applications because the virtual objects and displayed information can transfer effectively into the short-term memory, further exploration can convert knowledge into the working memory, and mastered skills can enter into the long-term memory. Also, the dual coding theory is the foundation for recognizing the effects of Augmented Reality. Students are presented with related multiple representations of information at the same time, increasing the learners' mental load. As a direct result, more overall learning is achieved. By human nature, people are social learners. The social learning theory supports the local and global collaboration, which results from AR application. These augmented experiences often allow students to model the behavior of professionals by applying factual knowledge to designs (Bitter & Corrall, 2014, p. 16).

Augmented Reality can extend the traditional classroom beyond the physical walls. The number of students carrying their own mobile devices grows exponentially every year. This technology connects classroom information to real-world environments. Students can be studying at certain locations and have access to overlaid media from the AR device through the use of GPS coordinates or QR codes (Antonioli et al., 2014, p. 99). Some experiences and simulations are already developed and marketed to educators; however, there are options for teachers to develop their own experiences. Augmented Reality tools are becoming more user-friendly and often require little to no programming skills, making them more attractive to the common educator (Antonioli et al., 2014, p. 100). When teachers develop their own AR experiences, they can share these resources with their colleagues as well as other school districts; eventually, this supplemental tool could become as available as a standard worksheet.

Disadvantages

With the advantages, there are also limitations. Students may feel frustrated if the application does not work properly as well as distracted if the technology is not implemented in the lesson effectively (Bacca et al., 2014, p. 144). Lessons will not always go as planned, especially in a high school setting, so teachers need to be aware that technical difficulties can occur, remain flexible, and have a back-up plan. Also, to avoid the distractions, AR should not be implemented into every lesson. Technology should not be used for the sake of using technology. This tool should only be used in lessons that would be improved by the technology, allowing students to engage in activities that they would not otherwise be able to experience (Bower et al., 2014, p. 7). Some training may be required for educators and students in order to understand how to utilize each Augmented Reality program to its fullest potential (Antonioli et al., 2014, p. 100). The Augmented Reality system may require significant storage space for virtual objects, a powerful processor to compose or display 3D-simulated objects in the real-world, and an interface that allows users to interact with the real and virtual objects (Bower et al., 2014, p. 2). There is also a possibility of including sophisticated software that goes beyond those basics, such as GPS technology, image recognition, and other features that enhance the overall experience (Bower et al., 2014, p. 3). Not all schools have access to devices, technology, or the Internet. However, most school districts have public libraries with these resources, and teachers can also write grants for their schools and classrooms (Bower et al, 2014, p. 2). Furthermore, Google offers reduced several cost programs for school districts and students (Thornton et al., 2012, p. 19). Teachers also have a difficult time letting go of their traditional approaches of direct instruction and permitting students to explore the learning environment on their own (Antonioli et al., 2014, p. 100). Many teachers feel uncomfortable transitioning from the "sage on the stage" to the "guide on the side" because they do not want to feel powerless or lose control of the classroom. Many educators believe that when administrators walk past their classrooms, the students should be sitting in silence in order to display good classroom management. The new learners, however, want an active role in the learning process; thus, the talking can be productive noise (Kiryakova et al., 2018, p. 557). This can be a gradual transition; change will not occur overnight. Newer teachers are entering the field that have grown up with digital technology. These teachers can share ideas and advocate for this style of learning (Antonioli et al. 2014, p. 101). Overall, there are several common limitations, but overcoming these obstacles is a very feasible task.

There are many uses of Augmented Reality, even extending beyond education. The use of AR systems have been "investigated in a range of industries since the early 1990s, including medicine, manufacturing, aeronautics, robotics, entertainment, tourism, and, more recently, social networking" (Bower et al., 2014, p. 3). The software can provide cognitive support for difficult tasks. Now, with the development of mobile AR, the system is widely accessible to regular consumers rather than simply residing in high-end laboratories (Bower et al., 2014, p. 3).

Educational Setting

Augmented Reality has the potential to play a large role in classrooms. This platform creates an environment that is consistent with the characteristics and needs of the present-day society and digital learners (Kiryakova et al., 2018, p. 556). In today's world, educators and students can design, build, and manage their own AR experiences by defining their own triggers and overlays using systems, such as HP Reveal (formerly Aurasma), Layar, Junaio, and BuildAR (Bower et al., 2014, p. 4). Most of these AR software applications are free to use and user-friendly. In 2012, sixteen high school students were invited to participate in an Information and Communication Technologies Innovations project, which aimed to explore the potential of Augmented Reality in school systems. The students selected sculptures of their choice within the university, and, afterwards, designed and created an AR overlay that was triggered by the sculpture. Later, those designs could be seen by visitors to the sculpture park in order to enhance their artistic experience. Before the task, the students went through a one-day workshop that provided an overview of AR along with a showcase of examples and hands-on tutorials. After the project, the students were asked to reflect on their experience. These students explained their process, obstacles, and successes with using the software. Before creating the AR experience, the students conducted substantial research on the history, context, and design of the sculpture. Then, they captured images of the sculptures, developed their own interpretations, and created prototypes of the design in order to anticipate the functions that their AR experience would include. Finally, they created the AR experience by organizing multimedia texts, including written words, images, and video explanations, which were launched by clicking certain overlays (Bower et al., 2014, p.11). By sharing their creations, a sense of value and worth was added to the assignment. Instead of completing textbook assignments, the students were encouraged to think differently, consider unique perspectives, and explore on their own, using curiosity as motivation. Higher-order thinking, creativity, and problem-solving skills can be promoted by having students design their own AR experiences.

The majority of research conducted on Augmented Reality in the educational setting has been focused on science. The technology has been applied to laboratory experiments, field trips, and scientific issues, including the control and spread of disease. The results declare that AR is effective for teaching abstract and complex ideas because the students do not have to rely only on their imaginations to envision these ideas, rather they can actually see it (Bacca et al., 2014, p. 139). Scenario-based simulations, gamification, and role-play-based experiences can enhance motivation while adding a sense of authenticity (Bower et al., 2014, p. 5). Beyond science, Augmented Reality, so far, has been applied mostly to the arts and humanities. This technology has been used in language learning, visual art and painting appreciation, and multicultural awareness (Bacca et al., 2014, p. 139). Augmented Reality has even been explored in social sciences, health and welfare, and more; however, AR tools are not yet commonly used in mathematics courses (Bacca et al., 2014, p. 140). Although, the very nature of mathematics would be an excellent host for this technological tool.

Mathematics Classroom

The role of an educator as a designer and facilitator plays a key role in the successful implementation of Augmented Reality in the mathematics classroom. If teachers use thought-provoking questions with relevant and meaningful experiences, the students will be able to learn from and be challenged by the activities, which produces deeper understanding and contributes to better learning outcomes (Bower et al., 2014, p.5). This technology also positively impacts the students' attitudes towards mathematics as they learn to apply the concepts in ways that are relevant to their lives outside of the classroom walls (Bower et al., 2014, p. 5). Furthermore, the mathematics curriculum can be differentiated through the instruction and presentation of the content as well as the assessment of objectives or standards by using the system to scaffold and tailor the learning process in order to meet the diverse needs of individual students.

Augmented Reality can be meaningful in the mathematics curriculum as long as it is implemented properly. "The National Council of Teachers of Mathematics, or NTCM, provides a vision for technology implementation in the mathematics classroom centered on the notion that technology has the potential to enhance mathematics learning, support mathematics teaching, and influence what mathematics is taught" (Estapa & Nadolny, 2015, p. 40). Educators cannot simply integrate this technology into random lessons without a definitive purpose. This platform enables students to engage in activities that they would not otherwise be able to experience (Bower et al., 2014, p. 12). This specific strategy needs to be implemented in lessons that would be improved by the technology. AR should only be used when it supports, facilitates, and improves the learning process through interactivity and engagement (Kiryakova et al., 2018, p. 556). Without this mindset or framework, "the application of technology within the classroom is often superficial and unproductive" (Bower et al., 2014, p. 7). When the use is meaningful and purposeful, the teaching has a holistic element in which the students no longer view concepts and ideas as an isolated set of factors or procedures (Thornton, Ernst, & Clark, 2012, p. 20). Teachers can follow the "SAMR" model, which stands for "substitution, augmentation, modification, and redefinition," in order to see if the technology will enhance or transform the lesson. It is a hierarchy that determines if the technology is merely acting as a direct substitute without a functional change or if it allows for the creation of new tasks that were previously inconceivable (Hamilton, Rosenberg, & Akcaoglu, 2016, p. 434). Another approach for educators is the "Technological Pedagogical Content Knowledge" model, or "TPACK." This framework serves to determine how the technological knowledge, content knowledge, and pedagogical knowledge all overlap to create meaningful lessons that support teaching and learning (Joo, Park, & Lim, 2018, p. 48). In order to serve this function, teachers can integrate technology standards into their lesson planning.

The AR technology provides learners with control over the actions of the virtual objects as well as the interaction with them. For instance, students can manipulate the position, size, shape, and other properties of the virtual objects and their alignment with the physical objects (Kiryakova et al., 2018, p. 561). The interactive features of this tool enables digital manipulatives that support hands-on learning (Salinas et al., 2015, p. 3). As a direct result, AR allows learners to discover, explore, and experiment with properties and behavior of objects that cannot be achieved in traditional settings.

Complex geometric shapes can be represented by their three-dimensional models, which would promote spatial thinking. Examples of pre-designed AR applications are Arlon Geometry, CleverBooks, Cyberchase 3D Builder, and Math Ninja AR (Kiryakova et al., 2018, p.563). Another application, Construct 3D, was specifically designed for mathematics education (Kaufmann & Schmalstieg, 2003, p. 1). This AR tool allows for the creation of three-dimensional geometric models along with curves and surfaces, and it allows multiples users, such as teachers and students, to share a virtual space collaboratively (Lee, 2012, p. 16). Additionally, Google has implemented AR technologies to allow students to learn through different software, while also frequently offering support and financial assistance for students. An augmented package, called ARSights, is completely compatible with Google Earth, Google 3D Ware-house, and Google SketchUp (Thornton et al., 2012, p. 19). Tinkercad is a beginner-friendly application tool which is beneficial in three-dimensional modeling (Bhaduri, Van Horne, Gyory, Ngo, & Sumner, 2018, p. 3). These tools will help to foster both visual and tangible learning of mathematics.

Spatial thinking was once considered an innate skill in students; however, many mathematics teachers have started to question that statement, especially when instructing about solids of revolution. Spatial visualization is often the basis for problem-solving, while also being a cross-curricular skill, so it would be beneficial to use a technological resource that supports this way of thinking (Salinas et al., 2015, p. 2). Problem-solving is an essential part of the classroom, and, often times, students do not have the opportunity to experiment and draw their own conclusions because the school lacks the funding and resources; however, students can continue doing experiments in AR, without exhausting materials, until they have mastered the concepts (Thornton et al., 2012, p. 19). Discovery-based learning encourages students to take risks, step outside of their comfort zones, be creative, and make mistakes without consequences (Thornton et al., 2012, p. 20). This is important because the learning process is enhanced when students play an active role in their own education.

There are many specific lessons in which AR would be an excellent supplemental resource within the mathematics classroom. For instance, many concepts can be modeled and applied with the context of the real-world. These students would be able to generate models and simulations that demonstrate the concepts. Afterwards, they can conduct tests, make predictions, view the model from various perspectives, and make adjustments. This style of learning converts the students' thinking from abstract to more concrete, leading to deeper understanding as they transfer the concepts into a part of their life that is meaningful and relevant (Thornton et al., 2012, p. 20). AR can also play an important role in calculus. For example, the students could graph in three-dimensional planes, rotate and revolve figures around an axis, visualize the behavior of integrals, determine areas under a curve, and more (Salinas et al., 2015, p. 6). In geometry classes, the students could determine surface area and volume using three-dimensional objects rather than two-dimensional images along with discovering and proving the properties and characteristics of various shapes (Lin, Chen, & Chang, 2015, p. 2). Additionally, Augmented Reality can help students work through cross-disciplinary subjects, such as completing design challenges in STEAM programs, which is comprised of science, technology, engineering, the arts, and mathematics (Bhaduri et al., 2018, p. 2). AR often aligns with the tools necessary to investigate within the scientific method and engineering process during these projects.

Case study. Research on Augmented Reality in secondary mathematics classroom is still in the infancy stages since the technology is fairly new. However, this tool has been used in small, rural schools to help to level the playing field for the students. One specific study, which took place in a rural high school in Iowa with fifty-six percent females and forty-four percent males, compared two geometry classes and two algebra classes, which were all taught by the same instructor. One geometry class and one algebra class were the treatment groups, while the other geometry class and algebra class were the comparison group. In the treatment group, students were given an AR-enabled activity packet, which triggered links to videos, audio, and visuals that physically appeared on the handout pages. The comparison group, on the other hand, was given the same handout and an additional website to view on the computer, but they were to complete the handout without the use of the AR devices. Throughout this study, pre-tests, post-tests, and delayed post-tests were given to the students in all of the classes in order to gauge their understanding of the concepts, mathematical processes and strategies, and accuracy of their solutions. The tests consisted of ten questions, which were selected from valid and reliable tests, such as the American College Testing (ACT), California Standards Test, and the Program for International Student Assessment. Significant findings were reported, and both groups improved from the pre-test to the post-test; however, the students in the AR treatment group had slightly higher scores in the post-tests and much higher scores in the delayed post-tests, almost a twelve percent better average, compared to the other group. This implies that the Augmented Reality tools provided the students with memorable, lasting connections. Student motivation was also assessed through a survey; the Instructional Materials Motivation Survey is a valid and reliable instrument used to examine the motivational impact of tasks and materials. This survey also included an open-ended question in which the students could reflect on their experience. The survey results from the group that used the AR lesson declared that the students more positively agreed that they would like to learn more about the topic, the lesson was eye-catching, and it instilled curiosity. In contrast, they also reported that, at times, they thought too much information was being presented to them. In the open-ended question, many students who used the AR-enabled handout stated that the lesson was "fun" and "interesting," whereas these words were not reported in the comparison group. Both groups stated that some of the questions throughout the handout were difficult; however, a higher rate of correct scores, nearly twelve percent higher average, was shown by students who had access to AR. The instructor noticed that the AR treatment group tended to be more focused and engaged than the comparison group (Estapa & Nadolny, 2015, p. 42-46). These results align with the patterns seen in other fields beyond mathematics.

Future Research and Exploration

There is a lot of potential for AR in the future mathematics classroom. For instance, there could be classroom overlays for teachers that contain grades as well as individualized education plans and background information on students, including medical and social information. Additionally, there could be alerts for behavioral issues along with recommended courses of action and places to log the occurrences (Bower et al., 2014, p. 13). Beyond aiding teachers, students could benefit from virtual field trips as well as becoming designers of the augmented world for future generations (Bower et al., 2014, p. 13). Furthermore, Augmented Reality textbooks are currently being designed. These textbooks, often called "magic books," contain interactive features that engage and motivate students to read and study through entertainment. These textbooks include much more learning content than traditional ones, and the material can be presented in multiple languages (Kiryakova et al., 2018, p. 562). When AR is applied to books, "people's fantasies about becoming part of the story become a reality" (Lee, 2012, p. 16). Students can turn the pages of the book, look at the pictures, and read the text without a device; however, with a handheld AR display, the three-dimensional models pop out of the screen. There is also room for more research in the exploration of the relationship between the rates of student achievement and the use of Augmented Reality in the classroom. It would even be helpful to determine how AR learning activities can be a part of blended instructional strategies, such as a flipped classroom (Ibáñez & Delgado-Kloos, 2018, p. 1). Further research on the design of instruction could also be completed in order to determine the optimal number of items in view as well as how it helps or hinders the learning. Also, it would be beneficial to explore ways to simplify working with three-dimensional models and planes for the common educator, using little to no coding and programming skills.

Limitations in this Research

Augmented Reality is still an emerging tool, especially in the field of education. For that reason, there are not a lot of case studies or research completed regarding AR in secondary mathematics classrooms yet (Kiryakova et al., 2018, p. 556). With limited resources available, it is difficult to gauge the complete impact of AR in the learning process, specifically long-term. This is an area that would need further exploration. Also, there were other limitations in this research process. Some AR software applications were not free; for that reason, these specific tools were not explored because they were assumed to not be as appealing to the common educator. There were also limitations with working in three-dimensional planes and models because this platform often requires knowledge of programming. However, predesigned options were explored to be implemented in the mathematics classroom. Finally, there was also limitations with time. If more time was available, it would be beneficial to explore the topics within the "Future Research and Exploration" section.

Conclusion

The main reason for shifts in the field of education is not the new technology, but the new learners with new needs and requirements. AR has the capability of engaging all students within the classroom, converting them from passive members into active participants, while fostering concrete connections and deeper understanding (Bacca et al., 2014, p. 134). Mathematics classrooms no longer need to be stationary; learning can occur anywhere with the aid of Augmented Reality at students' fingertips.

Figure 1. Layar Example

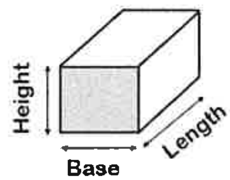
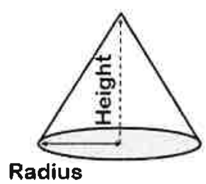
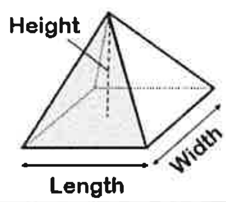
Shape	Name	Formula for Volume
	**Prism**	**Cross– sectional area x length**
	**Cone**	$\frac{1}{3}$ **x** πr^2 **x height**
	**Pyramid**	$\frac{1}{3}$ **x length x width x height**
	**Sphere**	$\frac{4}{3}$ **x** πr^3

Figure 1. This example was created using an AR software application called Layar. If students download the free Layar application on their handheld devices, they can scan the formula sheet (adapted from www.cazoommaths.com), and four links to YouTube videos (VividMath) appear that supplement the handout.

Figure 2. HP Reveal Example

Students can use AR to help teachers understand their thought process.

Figure 2. This example was created using an AR software application called HP Reveal. If students download the free HP Reveal application on their handheld devices, they can embed their thought processes on homework assignments, projects, and performance tasks. In this example, individuals can scan the words, "Students can use AR to help teachers understand their thought process," and a video will appear that demonstrates an example of a thought process inserted with Augmented Reality.

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