Augmenting Mathematical Education for Minority Students

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***Abstract*—The overall purpose of our research is to identify unique benefits and challenges in gamifying personalized augmented reality experiences in K–12 education for minority students. Gamification is applying game-like elements and principles in a non-gaming environment with the desired outcome of increasing engagement, motivation and learning. Augmented reality (AR) technologies project virtual objects onto the real world. Personalized AR potentially creates new levels of engagement for students while simultaneously accounting for their skill level, strengths, challenges and personal as well as cultural needs to increase learning. Using gamification in augmented or virtual environments is not a new phenomenon for researchers; however, the model presented in this work will leverage gamified AR experiences while incorporating cultural relevance to bring a new perspective for keeping minority students engaged and increasing learning outcomes.**

Keywords-augmented reality, culturally relevant, gamification, engagement

I. Introduction

In today's society, it is difficult for African Americans to find success in public school. A 2008 report submitted by the House Bill 2722 Advisory Committee states, "the education system was never designed to educate the diversity of students currently in public schools." As a result, there is a difference in test sores between various demographic groups of students. This is known as the achievement gap. A pivotal difference between these communities is the engagement (or lack thereof) for students to achieve expected goals. Every child wants to learn; however, every child is uniquely stimulated. Moving forward, we need to leverage cutting edge technology, e.g. AR, to engage and ensure all students develop science, technology, engineering and math (STEM) capabilities to levels beyond what was once considered acceptable [1].

A. Culturally Relevant Pedagogy

Despite remarkable efforts, the achievement gap between Caucasian and African American students remains due to key differences between the educational communities. These key differences are evident in the minimum of 21 points between the two ethnicities across core subjects [2]. African American students also often experience a disconnection in culture between their home and school settings which can factor into their underachievement [3]. In an effort to reach the academic and social needs of African American students, teachers have turned to infusing cultural elements into education in the classroom [4,5]. Researchers have defined culturally relevant/responsive pedagogy as using cultural characteristics, experiences and knowledge of ethnically diverse students to improve their academic success and develop them into culturally competent and critically conscious students [3,6,7]. One teacher has implemented this pedagogical approach by utilizing rap lyrics to discuss poetic aspects such as rhyme scheme and alliteration, while another engaged a classroom in solving a problem within the community using their math skills [3,5]. Research has shown that implementation of culturally relevant pedagogy has had positive academic success as well as positive reception from students [7-10].

B. Augmented Reality

Researchers have contributed to the AR educational literature by investigating the effectiveness of instruction for all students. However, previous researchers did not address how AR can be utilized to simulate learning for minority students. AR has been used as an assistive learning tool to deliver educational context to special needs students, investigate how working collaboratively in groups affects learning and how place-based pedagogies help connect learners to the culture of places [11]. This is a great starting point but the possibilities of AR has yet to be realized for addressing diversity in K – 12 classrooms. AR technologies have the potential to help minority students better understand mathematical concepts in the form of gaming by displaying gaming elements onto real-world objects in a meaningful way that is culturally relatable for them. In learning, gamified AR experiences could increase motivation, engagement and positively impact the cognitive process [12].

C. Gamification

The use of gamification in learning has been shown to improve student engagement, which can positively impact learning [13]. With the successful usage of game elements, e.g. rewards and leaderboards, the delivery of information in an activity can be transformed into an effective learning environment for students. Researchers suggest that this learning environment should include both real and

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simulated game elements; the experience should be as authentic as possible for learning to occur. The AR application should also provide instant feedback in authentic gaming environments. By providing feedback throughout the learning process, students' critical thinking skills and ability to work through their difficulties will increase. Applying game elements and feedback will enable students to work on contextual problems and symbolism so that they learn to apply abstract solutions in a fun and engaging way.

Both gamified AR and culturally relevant pedagogy can provide experiential, motivational, cognitive, and other psychological effects to students while at the same time engaging them [7,9,14]. Researchers have examined the potential use of gamification in AR applications to keep children engaged in learning without looking at theories of learning. In this paper, we create a model for how culturally relevant pedagogy can be incorporated into an AR application to teach geometric concepts in K-12. Our proposed model for the implementation and design of gamified AR education experiences aims to be more effective than traditional instructional methods due to the culturally relevant context, the learning activities, and hands on interactions used to deliver geometric concepts.

II. Related work

In a previous study, we conducted interviews to collect detailed information on teachers' opinions, and perceptions on how personalized AR can be implemented in the classroom. Before an AR-based learning tool is presented in K–12 education, the technology needs to be user tested with expert teachers [11]. If teachers are not comfortable with the technology, the chance of students successfully using it is greatly reduced. Current AR literature also highlights researchers' attempts at interface design with little basis in learning theories or educational psychology. Research is needed to better understand how learning and the roles of teachers and students can be used to inform the implementation and evaluation of AR applications. As such, we interviewed five teachers in the infancy stages of our research to bring a new dimension and perspective to the development of our gamified AR model.

A. Research Design

The previous study, *Teachers' Perceptions on Engaging Children in Math Education using Augmented Reality*, was conducted to generate knowledge from teachers on how AR paired with personalized learning can be used to effectively teach geometry to 3rd-5th graders. Semi-structured qualitative interviews was the methodology adopted for this study and then grounded theory was used to develop interactive learning methods that allow educators to create personalized learning interactions for each student. Each interview lasted approximately one hour. The interview started with questions concerning their current teaching practices, the current technology being used in the classroom and student assessment. Next, a demonstration of an AR application being used in a history course was shown to the teachers. After the demonstration, we asked questions such as: What features of AR can be incorporated into student learning? How can AR be presented to engage the students? Do you think student learning can be assessed using AR? How can personalized learning be integrated in the AR application?

Once the interviews were completed, the conversations were transcribed and analyzed to develop the methods based on the categories that are grounded in the data collected from the teachers. In open coding, we first read the transcripts and identified categories. Some of these emerging categories were engagement through games, collaborative teams, learning styles, constructivism, design based learning, etc. By comparing the data to the categories, we determined consistency in coding while making memos about how the categories were beginning to explain current teaching pedagogies. During the axial coding process, we used the codes and memos to show how the categories were related to each other. Some of the memos discussed the retention of geometric concepts, improving mathematics test performance, the degree of hands-on engagement needed to captivate students and how to assess student performance. From this, we revealed how we can customize the pace and deliveries of material to provide individualized attention and instruction. Lastly, selective coding allowed for us to construct the interactive methods to visualize how the personalized AR application will work inside the classroom.

B. Participants

A purposeful sample population of third, fourth and fifth grade teachers in the state of Virginia were used in this study. Using purposeful sampling, we were able to ensure that at least two teachers were within their first five years of teaching and the remaining of teachers had over ten years of experience. None of the teachers previously used AR in their classroom, but three teachers utilized other technologies. As researchers, we realized that the small sample size decreased the ability to generalize the finding of the study; however, it allowed us to form deeper interpretations of data for a specific population.

C. Results

Three interactive learning methods emerged from the semi-structured interviews. Our five teachers felt these methods were best suited to incorporate personalized AR into the K-12 environment.

In the first method, *Learning My Way*, teachers are not active participants during the learning activity. They play the role of a "guide on the side" while students collaborate with one another. The student's role in this learning activity is to engage with the AR technology in groups based on their learning style (e.g., visual, auditory, kinesthetic, etc.). Our expert teachers believe the personalized AR experience based on the students' learning style allows students to form a deeper learning of the geometric concepts presented.

In the *Reinforced Learning* method, teachers play a more active role in teaching the students geometric concepts. Once a lecture is presented, each student individually interacts with the AR technology. During this AR learning activity, the student will focus on the concepts that are the most difficult for them to understand. After the AR interaction, the students collectively come together and discuss all the concepts for reinforcement. Teachers expect that individual interaction with AR will increase student engagement because it's tailoring the learning modality to address their challenges.

The third method, *Gamification,* allows students to individually interact with AR technology while joining virtual teams. Within the virtual teams, each student is given a series of questions based on the geometric concepts learned. The questions become increasingly difficult and feedback is provided if questions are answered incorrectly. Points are awarded based on pace and accuracy of each individual student on the team. Teachers believe the real-time individual feedback will increase learning outcomes for students.

III. GAMIFIED AR MODEL

The results from the interviews served as a motivation to further explore the benefits of using method three, *Gamification,* in a learning environment. Our gamified AR model has the potential to increase learning in all students but it is needed more in the African American community to uniquely stimulate these students. The combination of gaming and AR directly appeals to African American students who are avid game players and tend to be synergetic learners [15,16]. Synergetic learners prefer tactile and cooperative learning, with the ability to fuse interpersonal relationships into learning activities. The aim of this model is for students to perceive their self in a real world gaming activity while learning geometric concepts and intertwining cultural aspects and experiences. Since the opportunity to use AR in the classroom to engage students has not been fully realized, the model will offer recommendations on how learning activities and hands-on interactions could be utilized to enhance learning gains and engagement.

A. Learning Activity

In this model, the learning activity should be designed to help students better understand the geometric concepts in a fun and engaging way. Using self-elements of gamification, the learning activity will individually help students identify, describe, compare, and contrast characteristics of plane and solid geometric figures by identifying relevant characteristics, including the number of angles, vertices, and edges, and the number and shape of faces, using concrete models in a 3D environment. The augmented reality setting is an excellent opportunity to interweave some of the nine interrelated dimensions of the African American culture. These dimensions are spirituality, harmony, movement, verve, affect, communalism, expressive individualism, social time perspective, and oral tradition. The energetic and engaging environment appeals to the dimension known as verve, which is an inclination for an increased level of stimulation [17]. The learning activity will begin with a mini lesson and/or narrative that ties geometry to a part of the students' culture. For contextualized learning to occur the student should answer questions related to the subject matter and identify problems within the gamified AR environment. If answered incorrectly, the student will receive positive feedback to reinforce concepts. This feedback is not only necessary as an educational aspect, but it also reinforces the affective and nurturing culture of the targeted students [17]. When correctly answered, the self- elements of points will keep students focused on competing with themselves and with classmates. Although healthy competition is encouraged and has been found to be beneficial in educational settings, it also important to incorporate collaboration amongst the students. The introduction of a group activity draws on the field- dependent nature of African American students. Field-dependent learners are communal learners and tend to remember information better in a social setting [18]. After using the AR application to solve individual problems, students will come together to work on a larger final problem in order to successfully complete the game. Once the game is completed, the students can draw on game elements of the activity and their own knowledge and imagination as they experienced it in the AR learning experience. Studies suggests that students in a gamified AR experience will have the ability to act and respond as though the learning activity is real, even if there is very little explicit visual support [6]. In conclusion, students will have increased engagement and motivation once they finished a learning activity of a gamified AR experience due to the gaming principles and positive feedback.

B. Hands-On Interaction

The AR application interface will allow students to interact with the real environment that is enhanced with virtual 3D game oriented objects. The overlap of AR objects on the real world scenes will allow students to transform what is considered an abstract idea into concrete metaphors for them to facilitate new and increased knowledge of geometric concepts. As relational learners, African Americans have a preference for movement and the opportunity for creativity [18,19]. Students can manipulate AR versions of real world objects that are relevant to their everyday life or aspects of their culture to further their understanding of abstract geometric concepts. With the hands on interaction of these gamified AR experiences, students may develop new schemas to encode the concepts and relationships experienced during the learning activity [21]. Allowing students to physically interact with visual representations of geometric concepts will produce learning gains that are difficult to achieve in other educational gaming environments. Incorporating hands on interactions

will provide guidance that directs the student through learning a concept in a simulated augmented reality. Instead of static text and images, the students can interact with open ended, abstract problems using dynamic graphics of game elements to strengthen geometric concepts. Researchers have predicted that students who encounter game-like elements during an AR experience will be more motivated to ask questions correctly and score points verse students who just view a gamified experience without AR [12]. In conclusion, allowing African American students to move about a physical space and interact with virtual and real objects will keep them engaged and enhance learning because of the instrumental role of gamified AR experience.

IV. Discussion

A. Objectives

We have three learning objectives that our gamified AR model addresses. These objectives were developed based on the Department of Education's Standard of Learning (SOL) for Virginia Public Schools. Objective one is for students to identify, describe, and analyze characteristics of solid geometric figures, e.g. circle, square, rectangle, triangle, and sphere) by identifying relevant characteristics. The learning activity meets this objective by using the AR application to display 3D images to illustrate shapes that is otherwise difficult for students to understand. While interacting with the AR application, the students will be presented with multiple choice, fill in the blank and sentence completion questions to earn rewards against their classmates to ensure they can describe and identify characteristics of solid geometric figures. The second objective is for students to identify and draw representations of points, line segments, rays, angles, and lines. During hands-on interaction, this objective is satisfied by asking the students to use their hand to draw lines, angles and rays onto real world objects. For example, a student could be asked to draw a right angle on top of their desk. The student that answers the question the fastest will move up on the leaderboard. The final objective is for students to investigate congruence of plane figures after geometric transformations, such as reflection, translation, and rotation, using mirrors, paper folding, and tracing. Through the incorporation of the learning activity and hands-on interactions, the students can interact with visually augmented representations of 3D shapes by manipulating the shapes with their hands. The collaborative interactions with teammates via the AR application to earn points will help the students develop spatial relationships for them to recognize the images of figures resulting from geometric transformations.

B. Implementation of Model in the Classroom

We will now present an example of how our model can be implemented in the classroom. Sports have been chosen as the cultural aspect to incorporate in a sample implementation of the aforementioned model. Sports are a large part of the African American culture, especially for males, as they provide a means of constructive recreation, a social and communal construct and sometimes an avenue of escape from poverty and undesirable living conditions [21]. In our example, the students will first be separated into virtual teams to provide them with opportunity for collaboration. Similarly to social networks, the AR application will connect students with each other utilizing Wi-Fi and Bluetooth to participate in collaborative activities. Once in the teams, a narrative story about athletes will be read to the students where they will serve as characters, inserting them directly into the learning activity. Each student will serve as one of the athletes. During the narrative, the AR application will project 3D graphics such as basketballs, the home plate on a baseball field, or soccer field goal onto elements in the classroom that correlate to each character.

On their own, students will get a chance to explore a virtually simulated football field, a basketball court and/or a baseball diamond. This allows students to be immersed in an authentic environment to appeal to the verve dimension. The AR application will ask students to identify geometric shapes or concepts located on their chosen sports arena. For example, the student is interacting with the simulated basketball court, if asked to identify a circle, the student will use their hand to select or draw a circle around the rim and/or the center circle of the court where the game is initiated. Once identified, students will be asked a series of questions related to the characteristics of the particular shape. If the student is taking on the role of a baseball player, the AR application will ask them to draw a line segment on the field from first base to second base. The AR application will provide real-time scaffolding in lessons to adjust to the student's needs, while adequately challenging them so that their understanding, and achievement level, grows over time. For questions answered correctly, students will be awarded points. If answered incorrectly, students will receive immediate feedback. Once enough points have been earned, students can enter a mode of free manipulation. At this point, they can interact with the shapes and investigate the ideas of reflection, translation and rotation.

After individual interactions, students will move onto the collaborative aspect of the lesson. Using the teams established previously, the students will collaboratively work together based on their characters. For example, the basketball players would work together to make several shots around the virtually simulated basketball court. Then they will be asked to identify the angel of the shot that was made. This creates a network for students to learn from each other while utilizing game-like elements. This example shows how our model can be executed in an authentic learning environment that allows students to meet all the objectives and investigate abstract concepts.

C. Implications

Currently, AR learning applications are not driven by pedagogy but more by the strengths and weakness of the authoring of the AR application. Our model leverages the culturally relevant pedagogy to design instruction to teach geometry to third, fourth, and fifth grade students using gamification and AR. Through the model, students can connect with other students of the same cultural background to participate in collaborative activities such as asking questions if they are left puzzled by a problem, or playing a game against each other where geometry is the focal point using AR. This creates a network for students as well as teachers to learn from each other and participate in augmented learning environments that has not be realized by other researchers.

Gamifying an AR experience can uniquely provide authentic learning environments that are potentially more engaging than traditional educational settings [11]. Our proposed gamified AR model supports how AR and gamification can be used to enhance students' engagement and learning gains while providing individual learning opportunities of geometric concepts. The inclusion of culturally relevant material allows African American students to feel more connected to an otherwise unrelatable subject. Using meaningful and relatable context can potentially increase the students' confidence in themselves and their ability to perform successfully academically [14]. The model is further expected to be helpful for other researchers to better understand how learners should interact in learning experiences using personalized AR combined with gamification and culturally relevant material.

V. Conclusion

We have created a model using cultural relevance as a pedagogical approach that leverages personalized AR and gamified experiences to increase learning. Although there is no literature on the combination of personalized AR experiences, culturally relevant pedagogy and gamification, we believe our model will be successful since individually the concepts have been shown to increase engagement and learning outcomes. Rather than attempt to change the actual material that students learn, this model aims to enhance the way students learn by enabling tangible, relatable and interactive experiences in a gaming AR environment. The three concepts (especially culturally relevant pedagogy) will likely keep African American students engaged and motivated while aiding them in retaining geometric concepts.

VI. Future Work

To understand the impact of AR systems built for educational purposes, we plan to conduct user studies in authentic environments to evaluate the strengths and limitations of our model. We also hope to combine culturally relevant pedagogy and gamification in other areas of math education, such as Algebra. Due to the transition to abstract concepts and other misconceptions in prerequisite content areas, students often struggle with being successful in algebra, "the gatekeeper" to higher math. We plan to investigate the use of a dance application and gamification elements as a means of reinforcing pre-Algebraic concepts to engage and improve academic performance for minority students.

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