Real World Geometry

Supplemental Geometry Instruction via an Augmented Reality Application

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1 INTRODUCTION

Geometry is an essential area of mathematics but considered difficult by kids when they first access it in school. By learning geometry, students may be able to identify shapes and space around them. However, kids know 3D shapes even before going to school. They intuitively investigate and interact with 3D shapes/objects by exploring it, since everything around us is three-dimensional. Then they go to school and learn to write and draw in two dimension [5]. It is getting more challenging that after kids already know that everything at school is 2D, they need to learn 3D geometry. Unfortunately, traditional teaching methods failed to assist kids to smoothly transition from 3D to 2D and go back to 3D. In addition, due to kids' own cognitive gap between 2D and 3D shapes, it is hard for them to get knowledge of geometry. Therefore, it is the time for teachers/parents seeking a new perspective to help kids with geometry learning.

In recent years, digital technology is employed in education since technology tools are very interesting and engaging for kids [1, 2, 6, 9]. Augmented Reality (AR) is one of the most explored and successfully used technologies. According to Piaget's Constructivism theory [4]. Kids easily acquire new knowledge if learning occurs in a specific context and is embedded in a physical environment. Thanks to AR, it allows users to be completely immersed inside a synthetic environment, which makes learning more effective [3]. Since AR permits to create interaction experiences that are enhanced by the overlapping of information between virtual and real objects, it improves the involvement of kids during their learning process [8].

In 1999, van Hiele proposed a theory named "Levels of Geometric Thinking", which claimed that the geometric thinking could be divided into four levels, from "lowest" to "highest" were: visual level (figures were judged by their appearance), the descriptive level (figures were the bearers of their properties), the informal deduction level (the properties of figures were logically ordered) and the deduction level (used axioms, definitions, theorems to identify figures [10]. The best way to help kids develop geometric thinking was to follow the sequence from lowest level to the highest, i.e. developing thinking from the visual level and gradually transition to the descriptive level, at the end reaching to the final deduction level.

2 PROBLEM STATEMENT AND RELATED WORK

2.1 Problem Statement

Because~~Due to the reason that~~ geometry plays an essential role in math and because it may be~~but is~~ too abstract for kids to learn, a new method which helps kids to build a connection between 2D and 3D geometry, develop spatial imagination and the capacity of abstraction geometry is necessary ~~urgent~~. Augmented Reality (AR), as a promising technology, allows kids to be completely engaged in the environment. Moreover, some AR-based multimedia is able to display both 2D and 3D objects by showing every part of the objects in detail [7]. Based on the above reasons, our goal for the project is to develop an AR app that makes ~~tangible~~ the geometric properties they learn about. Each level of the app includes~~will include~~ three steps (based on van Hiele's "Levels of Geometric Thinking"): (1) visual identification (2) kids interact with their environment in AR to discover geometric ideas (3) combines conceptual content (definitions and characteristics) with procedural content (applying formulae and calculus). Our app provides~~will provide~~ a new perspective for kids to better understand geometry, and increase geometry motivation and mathematics with AR.

2.2 Related Work

There are some AR based geometry learning applications. For example, Arloon Geometry is an application designed for middle school students (> 11 years old) to improve their 3D thinking skills. This application features 3D models with AR for most geometric shapes, such as pyramids, prisms etc., and the pupil interacts with the game by viewing geometric shapes from all angles and listing their properties and the formulae that define their area and volume. However, this application requires an Android system and is not suitable for younger kids. Shapes 3D is another AR based application which allows students to interact with real 3D shapes by placing solids everywhere and even rotate a 3D shape to better understand the geometric shapes. However, due to the complexity of this application, it does not implement AR technology with detecting objects. Kyle Wang and Ray Patt's last year's project, Real-World Geometry, includes three steps: kids identify shapes through visual identification, using AR interact 3D geometric shapes to identify them, and the highest level is interacting with the surrounding environment to better understand geometric concepts. This application is very promising, but due to time limitations, they only applied to three simple shapes, and did not reach to the highest level, deductive thinking level.

3 NEED FINDING

We performed~~plan to perform~~ need finding using interviews with domain experts. Here we define domain experts as teachers that have experience working with K-5 children and that have experience teaching basic geometry. We contacted friends and family that we knew with experience teaching/tutoring geometry~~will send out an email to education majors at the University of Delaware~~. Our goal is to get an sufficient understanding of what material students struggle with the most and therefore get an understanding of what topics our app should address. We also want to get guidance for how to best communicate instructions to these students and what techniques tend to keep them engaged. A sample interview protocol is included in appendix A.

We were able to interview two friends with some limited interest/experience in teaching. One was a student who hopes to become an elementary school teacher and other was a friend with experience babysitting and helping 1st-5th graders with homework. Neither of them had experience teaching classes entire class on geometry, but both had some one-on-one experience and knowledge of the area.

The most significant difficulty they sited was student's difficulty differentiating between similar shapes, such as differentiating between a rhombus and a parallelogram. Both had used web resources to help teach material, and both said that they could see an application as helpful for teaching the material (although one of them noted that a tablet game might be better as the larger screen would be easier for them to interact with).

These findings indicate that our application will potential serve an important niche as it could provide a student with extra practice so they can get better disguising between those similar shapes. It also highlights a possible need for us to in the future expand the app to focus on these shapes, as it might be more beneficial for our app to ask students questions about more difficult to identify shapes like the ones sighted by our interviewee. This also motivates further work towards developing a tablet version of our game for the reasons cited above.

4 PROTOTYPING

Our first version of prototype is using storyboards made via Miro for the interface design (appendix B). The detailed procedures are explained as following: at the beginning, parents are required to register and help their kids to login the app. This aims to help us track kids' progresses and watching their learning behavior. Second, the screen shows several different levels and kids can go to next level after they complete their current level. This design is inspired by many kids' games, which gives them more control and encourage them challenge harder level. After choosing a level, users will select either "Learn the Basics," "Real World Match," or "Exploring Some Math!" This design is consistent with Van Hiele (1999)'s hierarchical theory of geometry thinking, from "lowest" to "highest": visual level, the descriptive level and the deduction level. Only level two ("Real World Match") implement AR, which let users learn geometry shapes by explore their environment. The first level, "Learn the Basics", uses simply let the user visually learn a geometric concept using the 2D environment. The third level, "Exploring Some Math," let kids learn geometric shapes from visual and description to the deduction learning, combines conceptual content (definitions and characteristics) with procedural content (applying formulae and calculus). We also designed to put some pop-up quizzes to evaluate their performance.

We focus more on breadth of the features we covered rather than depth; we aim to show the majority of the features involved in our application, but our prototype will not implement any real functionality.

5 IMPLEMENTATION

We used ARKit (an augmented reality framework included in Xcode) with SceneKit, the 3D graphics framework, created our augmented reality app on iOS devices (built in Mac pro and implemented in iPhone 7plus). ARKit allowed users place digital labels on 3D objects in the real world by blending the camera on the screen with virtual objects and interact with these objects in a real space.

A schematic of our solution can be found in in appendix B and the source code for our final implimentation can be found at https://github.com/HCI-UD/finalproject-1-geometry

This app is an extension of previous Kyle and Ray's work. As described in the storyboard, "Learn the Basics", uses no AR and simply let the user visually learn a geometric concept using the 2D environment. Feedbacks are given for both correct and incorrect answers. "Real World Match" implements AR technology, has the user explore their environment and uses his current 2D shape information to match 3D real world objects. Current, we pre-scanned real-world objects (e.g. a box with two square faces) with ARKit Scanner (Apple provided program) and then let users identify square object in their surrounding environment. Users can walk around and search the object from many perspectives. After they find an object with square faces, a dialog indicator will show up and confirm their correct identification. "Exploring Some Math," gives users formulae and let them do some calculation. In the future, this app should have more pre-scanned 3D objects and extend to complex 3D shapes identification. In addition, in the "Exploring Some Math," part, we plan to add some pop-up quiz to track performance and add similar shapes' differentiation part to have users better understanding each shape's property. During the time of app developments, we have faced several challenges. First of all, object detection requires accurate pre-scanned 3d models, it's hard for us to cover all shapes (due to lack of edges of balls, scanner is hard to detect circle objects). Second, our app is targeted to K-3 kids, it's hard for us to find and get parents' approval to interview this age kids. ~~We will continue work on the IOS app that the previous Real-World Geometry team developed. Therefore we will continue utilizing the Swift programming language for front-end development and ARKit 2 for AR implementation. In a addition to original Real-World Geometry app's features, we plan on adding functionality for users to perform mathematical calculations on the geometric shapes they identify. One challenge we may face is the need to balance our goal of adding new and interesting features to the existed application with our desire to maintain a simple and easy to use interface for our users. We will address this by ensuring that we always~~

~~prioritize user experience as we add to features. A schematic of our solution can be found in our prototype storyboard in appendix B. This describes the steps the user will be taken through as they interact with our application. We are building a mobile app, and are currently targeting only iPhones. Hopefully will eventually be able to expand to android phones as well. We view a mobile app as the best medium for this project, as children will likely be familiar with mobile apps, and mobile app will allow us to easily access a camera which will be necessary for the AR functionality that the app will utilize.~~

6 USER STUDY / EVALUATION

6.1 Methodology and Recruitment

The goal of our user study was~~will be~~ to assess the effectiveness of our project and motivate future changes that could be made to the app. We performed~~Will perform~~ this in one human subjects study where we collected~~will collect~~ quantitative and qualitative information about the users' experiences using our application.

We ~~will~~ evaluated~~evaluate~~ the following hypothesis question: Does usage of our application improve student performance on geometry assessments when compared to traditional teaching methods?

We planned on recruiting elementary students to participate in our study but because of time constraints, we were only able to recruit one participant, Jie's daughter (a 6-year old)~~We will recruit elementary school students to participate in our study (likely through family/friends for convenience)~~. ~~The students will be asked to take a short geometry pre-assessment. We will conduct a between subjects experiment where students are exposed to one of two conditions: (1) a traditional teaching method simulated through a short video that explains geometric concepts (this is our baseline condition) (2) our Real World Geometry application. After this we will assess students from both groups on the same geometry assessment. We will then compare score improvements for each group, look to see if there is a significant difference between them. We will ask the students assigned to condition 2 to take a brief survey, to get a better understanding of their experience using our application.~~

We had planned on conducting a between subjects experiment in which we would compare the benefits of our application when compared to traditional geometry instruction. We would have evaluated improvements in performance on geometry quiz comparing the changes in students scores before and after using our app against the changes in students scores before and after watching a short pedagogical video on elementary school geometry. Here the video condition would be the base baseline that we would evaluate performance against, as the video would simulate the traditional geometry education approach that we are trying to improve with our app.

Because of time constrains, difficulty recruiting, and difficulty sharing the app remotely, however, we instead had to conduct a smaller study in which we had one participant use the application for a brief period of time and share information about their experience with the application. We asked questions listen in the questionnaire, included in appendix C.

6.2 Results and Discussion

Our participant reported that while they enjoyed using the app they didn't feel as though they learned much from using it. They cited previous knowledge of all of the shapes shown in the app as the main reason why they didn't learn anything from using it. They also said that they were unsure if the equation information improved their understanding of geometry.

This findings indicate that future development should focus initially on adding more shapes to the app, as this appears to be it's greatest shortcoming as of right now. As of right now we cannot say that our solution outperforms existing solutions as we were not able to properly evaluate it against other approaches to geometry education and because our results indicate of room for improvement.

6.3 Limitations

Our study's greatest limitation is our lack of participants. As a result we were not able to conduct an experiment that effectively compared our app to alternative teaching methods, and because we only have one participant we cannot really generalize our findings. As a result an additional users study is likely necessary to fully evaluate the effectiveness of this application.

6.4 Future Work

If were were to start again, we would do several things differently. The primary thing we would have changed would be to collect more need finding information earlier in the process, as this could have better guided the development of our application.

Future work should focus on the issues discussed in the need finding discussion (Section 3) and in our results and discussion section (Section 6.2). Specifically future development should focus on implementing a tablet version of the app, as users might not have the motor skills to interact with a mobile application, but would likely be able to more easily use a tablet application. It is also quite clear that more focus should be put on implementing games that give users the opportunity recognize more shapes and to differentiate between more similar shapes, as our study indicates user desires for the app to contain more shapes, and our need finding research indicates a need to tasks that let students practice similar shape differentiation.

7 ALTERNATIVE APPROACHES

We planned to use ARKit 2 and paired it with Unity, however, it also has downsides, e.g. only supporting macOS and iOS systems. We prepared some backup plans: first, we can build AR with Vuforia with Unity or ARCore with Unity, because we can run it on Android system; second, we can also try ARToolKit5, since it is fast, intuitive and cross-platform, and can be run on macOS, iOS, Linux, Android or Windows. We also explored AR.js, a web-based approach to AR application development. In the end we ended up use ARKit 2 because it allowed us to build off of the existing Real World Geometry codebase without having reimplement existing features.

8 TIMELINE AND DELIVERABLES

(1) We finished our storyboard during the week of October 25, 2021. (All the member)
(2) We discussed and finished our first draft proposal (also presented in class) during the week of November 1st, 2021. (All the members)
(3) We wrote~~plan to write~~ our second draft proposal during the week of November 15, 2021. (All the members involved discussion, each member was responsible for at least two parts and at the end modified and finished together)
(4) We wrote and ran~~plan to write and run~~ the code during Thanksgiving week (November 22, 2021) (Jie~~Jie and Connor~~) and also design and work on our survey~~, observations part.~~ (All the members)
(5) We finished~~plan to finish~~ the detailed user study/evaluation part during the week of December 12~~November 29~~, 2021. (All the members)
(6) This project is expected to be completed by December 17, 2021. (All the members)

9 BIOGRAPHIES

Jie Ren

Field of Study Computer Science

Role Application development, proposal writing, background research, application design/prototyping, creation of the video demonstration

Interests Software Development, Network Security

Connor Onweller

Field of Study Computer Science

Role Website development, initial study design, editing, proposal writing, application design/prototyping, study analysis

Interests Computer Accessibility, Computer Vision, Software Engineering

Tong Chu

Field of Study Biomedical Engineering

Role Application design/prototyping, updated study design, survey construction, proposal writing

Interests Medical Design experience (Patent Pending)

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Appendices

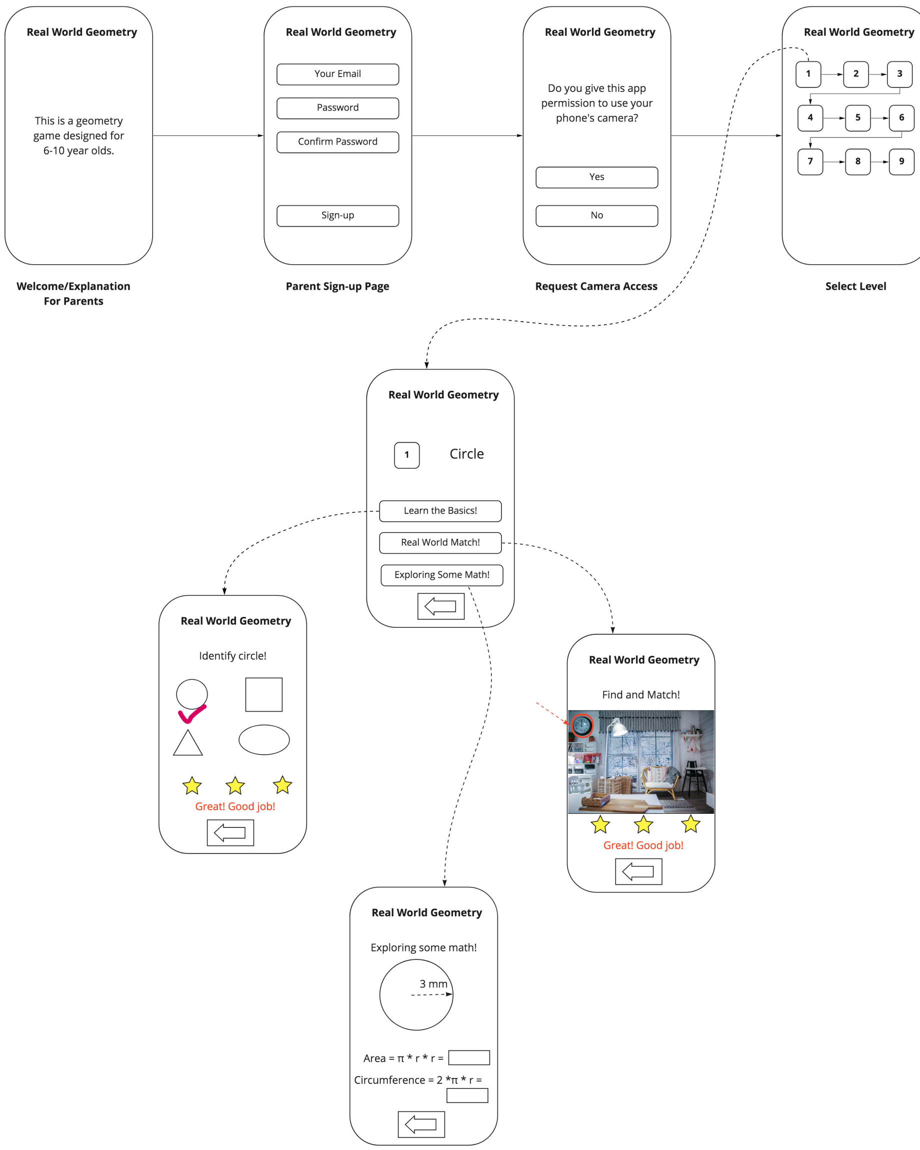
A INTERVIEW PROTOCOL

(1) **Introduction**
Hello, my name is ______. I am a student at the University of Delaware studying the role that augmented reality software can play in geometry education. I am looking to gain some insight on your experience teaching students geometry.

(2) **Questions**
- What grade do you teach?
- How many classes do you typically spend covering geometry per year?
- Do you enjoy teaching geometry?
- Is teaching geometry ever difficult? If so, what kind of things make it difficult?
- Do you ever use resources like videos, websites, or games to help teach? If so, do you ever use any of these to help teach geometry?
- Could you see a geometry phone game as something that could be a helpful supplementary tool for teaching?
- What topics would you think such a game should cover?
- How do you best communicate instructions for students to complete activities, assignments, and games? What types of considerations should be made when doing so

(3) **Conclusion**
Thank you for participating in this study. We will send you an update when we complete our paper.

B PROTOTYPE


Real World Geometry
This is a geometry game designed for 6-10 year olds.
Welcome/Explanation For Parents
Real World Geometry
Your Email
Password
Confirm Password
Sign-up
Parent Sign-up Page
Real World Geometry
Do you give this app permission to use your phone's camera?
Yes
No
Request Camera Access
Real World Geometry
1
2
3
4
5
6
7
8
9
Select Level
Real World Geometry
1
Circle
Learn the Basics!
Real World Match!
Exploring Some Math!
Real World Geometry
Identify circle!
Great! Good job!
Real World Geometry
Find and Match!
Great! Good job!
Real World Geometry
Exploring some math!
3 mm
Area = π * r * r =
Circumference = 2 *π * r =

C USER STUDY QUESTIONNAIRE

Survey for Kids

This survey is design for 3-8 years old kids to help the web/app designer improve their approach to the implement and refine of "1 Geometry" mobile application.

1. Question 1: How many geometry shapes have you already known before using this App? 1 point

   Mark only one oval.

   - 0-1
   - 1-3
   - 3-5
   - more than 5
   - Other: ____________

2. Question 2: How many more shapes you learned after using this App?

   Mark only one oval.

   - 0-1
   - 1-2
   - 2-3
   - Other: ____________

3. Question 3: Does the equation we provided help you to understand the math?

   Check all that apply.

   - [ ] Yes
   - [ ] No
   - [ ] Maybe?
   - Other: [ ] ____________

4. Question 4: Do you like this App overall

   Check all that apply.

   - [ ] Yes, I like it very much
   - [ ] I like it overall but expect it to be developed
   - [ ] I don't think this App is awesome
   - Other: [ ] ____________

5. Question 5: Do you have any suggestion for us to make improvement?

   ____

6. Question 6: How old is your kid (the person who played with the App)?

   Mark only one oval.

   - 3-5
   - 5-7
   - 8-10
   - 10-13
   - 13+
   - Other: ____________