Discovering Educational Augmented Reality Math Applications by Prototyping with Elementary-School Teachers

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ABSTRACT

In recent years, augmented reality (AR) applications for children's entertainment have been gaining popularity, and educational organizations are increasingly interested in applying this technology to children's educational games. In this paper we describe our collaboration with teachers and game designers, in order to explore educational potential for AR technology. This paper specifically investigates the topics of: What mathematics curriculum topics should technological innovations address in the Grade 1-3 classrooms? Which of the topics are suitable for AR games? And, how can we facilitate an efficient dialogue between educators and game designers?

Keywords: Augmented Reality, Prototyping, Mathematics, Elementary Classroom, Pedagogy, Teachers

Index Terms: H.5.1 [MULTIMEDIA INFORMATION SYSTEMS]: Information Interfaces and Presentation - Artificial, augmented, and virtual realities

1 INTRODUCTION

The elementary-school mathematics classroom is an ideal place for augmented reality, as children are moving from playing with physical toys, to understanding abstract numerical concepts. The capabilities of AR technology of overlaying digital information on physical objects, allows for the creation of games that bridge physical and abstract content, potentially allowing students to learn difficult math topics more easily and in a more engaging manner than using traditional approaches. Existing research projects have investigated educational AR applications for mathematics (ex: [1,2,3]) and various other STEM topics (ex: [4,5,6]). However, more research is needed to understand which specific curriculum topics are 'valuable' to address using augmented reality applications. Specifically, in the present work we aim to identify which mathematics curriculum topics are causing difficulties for elementary-school teachers, and to identify which of these topics should be addressed through future augmented reality applications.

2 PROBLEMATIC CURRICULUM TOPICS

We executed a qualitative needs assessment study, focused on identifying existing problems with the mathematics curriculum. We recruited fifty Grade 1-3 teachers to review mathematics Common Core State Standards (CCSS) for their grade level, and to rate each standard according to how difficult it is to teach with the tools and approaches available to them in their classrooms. If teachers rated a standard as "difficult," they were prompted to explain why it was difficult to teach in a survey comment box. Our expectation was that technology designers would then identify curriculum topics that can be addressed by the capabilities of present-day AR technology, and these could serve as valuable core educational topics for future AR games.

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Table 1. Curriculum topics, teacher reported difficulty, and AR suitability.

Mathematics curriculum areas	Teaching difficulty	Match with AR technology
Notation, Vocabulary and Word Problems	High	High
Counting and Cardinality	Low	High
Measurement	Low	High
Geometry	Very Low	High
Fractions and Number Lines	High	Medium
Representing Numbers and Data	Medium	Medium
Place Value, Decomposition, and Operations	High	Unclear
Organization	Medium	Unclear
Automaticity	Medium	Unclear

The needs assessment study generated a list of math topics that serve as valuable starting points for future educational tools. Table 1 shows the list of mathematics topics rated as difficult to teach in Grades 1 to 3 classrooms, and the degree to which teachers and researchers determined AR to be a possible solution to addressing teachers' needs in these curricular areas. The suitability of matching AR technology to a curriculum topic was determined based on several dimensions related to AR technology's unique affordances that separate it from existing classroom tools [6]; specifically, a curriculum topic was rated as a good match with AR if students can benefit from 1) visualizing the mathematical content in three dimensions (ex: visualizing volumes), 2) visualizing the content through multiple representations at the same time (ex: seeing physical and numerical representations together), 3) physically interacting with mathematical topics (ex: physically enacting number decomposition), or 4) having in-context access to additional information (ex: accessing definitions for words in a word problem).

3 PROTOTYPE DESIGNS

Based on the needs assessment study, we constructed several prototypes for camera-enabled handheld devices.

Word Problems Prototype: In this prototype, when the child points the device camera at the word problem, the application allows the child to progress step by step through the mathematical components of the problem. The 3D story visualization occurs in the context of the child's existing practice of solving problems on paper.

Nonstandard Measurement Prototype: In this prototype, children are asked to measure a specific distance (ex: of 3 units) by using the nonstandard measures of “puppy paws”. If students do not perform the measurement correctly (ex: by overlapping the paws, or by leaving a distance between the paws), then the application indicates the problem to the student through the emotive virtual pet.

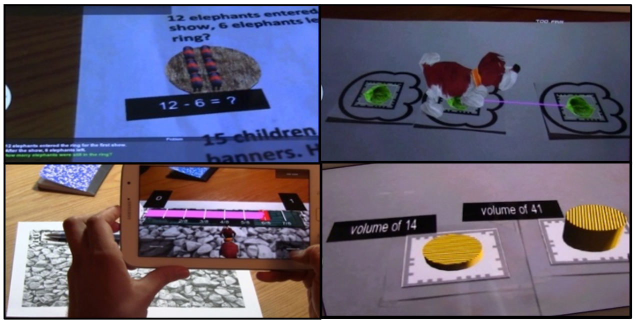

Figure 1. Prototype applications. Top: word problems and nonstandard measurement. Bottom: objects as fractions, number representations.

Objects as Fractions Prototype: The student can place an arbitrary physical object within a paper number line. The application then measures the length of the object, and displays a fraction that corresponds to the object’s physical size, relative to size of the number line. The student is free to modify the denominator of the fraction, and the software updates the numerator in order to keep the fraction amount relatively constant.

Number Representations Prototype: Through the mobile application, students can look at two numbers and visualize different representations such as groups of unit cubes, cylindrical volumes, sets of puppies, etc. The student can physically interact by moving these representations, observe them from different angles, make guesses and estimates, and compare between different number magnitudes and representations

4 EVALUATION AND TAKEAWAYS

Three elementary school teachers were recruited from San Francisco Bay Area public schools and interviewed about the prototypes. The research team then used qualitative methods to examine the data and reflect on the process of involving teachers in different stages of prototyping activities. The following sections present our most salient takeaways.

Curriculum Topics Suitable for Augmented Reality: The curriculum topics identified as especially suitable for augmented reality applications are listed in Table 1. With the exceptions of the fractions prototype which had pedagogical design flaws, teachers were enthusiastic about the educational potential of the prototypes, and mentioned that they would use them in the classroom once they were refined as educational products.

Expect Frustration When Working With Novel Technology: During early paper-based brainstorming activities, teachers did not understand the capabilities of the technology and would sometimes suggest far too futuristic ideas for AR games, or suggest non-AR application ideas; and similarly, technology designers did not entirely know how to properly create educationally appropriate content from the identified needs. More effective was the process of discussion around hi-fi prototypes, as this facilitated identification of concrete design ideas for how AR can be used in classroom educational applications.

Hi-Fi Prototypes Will Create Tunnel Vision: The high fidelity prototypes were needed to properly illustrate the high degree of physical interactivity in AR applications. However, when teachers were exposed to high-fidelity prototypes, they were often biased to offer feedback on surface design elements, and that was sometimes not fruitful for early design exploration.

Educators and Students Could Be More Involved in Design: Although teachers are not game designers, they are intimately familiar with how children think and what children find entertaining; thus, teachers can provide valuable feedback for how to turn a core prototype idea into an engaging game. We envision that, as designers respond to the teacher feedback and update the AR application prototypes, it will be beneficial to have several more iterative feedback sessions with teachers, educational experts, and formal evaluations with students.

An Open Door for Further Research: In Table 1 we have identified curriculum topics which are difficult for educators to teach with current tools and approaches. We hope that this list will serve as a guide for future research studies investigating the design of AR and non-AR educational applications, in order to address topics that are valuable to educators and students.

5 CONCLUSIONS

Through the prototyping activity we have explored only a few possibilities for addressing the curriculum topics identified as difficult to teach in the elementary-school math classroom. It may be possible to create other applications that target the same topics, and it may be possible to create applications that are effective at targeting the topics we have marked as unsuitable for AR. We hope that future research continues to investigate the suitability of AR games for addressing elementary-school classroom topics. We further hope that more research is done to analyse curriculum difficulties for other subjects in the elementary school curriculum, and to highlight problem areas that could be addressed through technological innovations. In addition, further research is needed to understand how teachers and game developers, though their collaboration during the design process, can create new ways to represent educational content, and in turn create new ways for students to construct knowledge.

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6 REFERENCES

[1] R. Roberto, et al. "A dynamic blocks platform based on projective augmented reality and tangible interfaces for educational activities." *Virtual and Augmented Reality (SVR), 2013 XV Symposium on*. IEEE, 2013.

[2] H. Kaufmann. "Construct3D: an augmented reality application for mathematics and geometry education." *Proceedings of the tenth ACM international conference on Multimedia*. ACM, 2002.

[3] K. Bujak, et al. "A psychological perspective on augmented reality in the mathematics classroom." *Computers & Education* 68 (2013): 536-544.

[4] M. Billinghurst, and A. Duenser. "Augmented reality in the classroom." *Computer* 7 (2012): 56-63.

[5] M. Dunleavy, C. Dede, and R. Mitchell. "Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning." *Journal of Science Education and Technology* 18.1 (2009): 7-22.

[6] I. Radu, "Augmented reality in education: a meta-review and cross-media analysis," *Personal and Ubiquitous Computing,* vol. 16, pp. 1533-1543, 2014.

[1] However, the contents of this paper do not necessarily represent the policy of the U.S. Department of Education, and readers should not assume endorsement by the Federal Government.