Prototyping Augmented Reality With Elementary Mathematics Teachers

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 an effective process of collaboration between teachers and game designers, in order to explore educational game ideas 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? Through a process of needs assessment and prototyping activities, we engaged with elementary school teachers in order to understand these questions.

Author Keywords

Introduction
Augmented reality (AR) is a technology innovation that enables computer-generated imagery to be superimposed on a video-camera view of the real world. There are many potential benefits which augmented reality technology could bring to children’s lives, such as enhanced entertainment through whole-body interaction [1], advancing education through in-situ interactive visualizations [2], and improving rehabilitation and skill development through physical manipulation [3]. In the domain of learning, augmented
reality has been shown to have measurable benefits over traditional approaches when experienced by K-12 students and adults [4].

Not many educational AR applications or games have been developed for this context, yet the elementary mathematics classroom seems an ideal place for augmented reality. At this age, 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. Therefore, this technology may be a valuable tool for the elementary math classroom.

### Problematic Curriculum Topics

From our early conversations with educators, we determined that it is not efficient to simply ask educators to brainstorm game ideas about what could be done with this novel technology. We found that many educators are not fully aware of the technology’s capabilities and limitations. To elicit effective ideas and feedback from teachers, our approach was to execute a 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.

The needs assessment study generated a list of math topics that can 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 [4, 5]. Specifically, the match between AR technology and a curriculum topic was rated highly if teachers and researchers determined that students could benefit from:

1) Visualizing the mathematical content in three dimensions (ex: visualizing volumes),
2) Visualizing the math content through multiple representations at the same time (ex: seeing physical blocks and their numerical representations),
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).

<table>
<thead>
<tr>
<th>Problematic curriculum areas</th>
<th>Teacher reported severity</th>
<th>AR Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notation, Vocabulary and Word Problems</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Counting and Cardinality</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Measurement</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Fractions and Number Lines</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Representing Numbers and Data</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Place Value, Decomposition and Operations</td>
<td>High</td>
<td>Unclear</td>
</tr>
<tr>
<td>Organization</td>
<td>Medium</td>
<td>Unclear</td>
</tr>
<tr>
<td>Automaticity</td>
<td>Medium</td>
<td>Unclear</td>
</tr>
</tbody>
</table>

### Prototype Designs

All the prototypes were designed to use camera-enabled handheld devices, and implemented in the Unity3D platform.

**Prototype 1: Visualizing Word Problems**

In this prototype, when the child points the device camera at the word problem, the application presents a breakdown and visualization of the word problem, and 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. As the child works through the word problem text, the application illustrates the items, actions and numbers involved in each step of the word problem.
Prototype 2: Number Representations
Through the mobile application, students can look at two numbers, and the application will visualize the numbers in different representations such as: collections of randomly scattered unit cubes, unit cubes aligned on a number line, unit cubes grouped by 10s, cylindrical volumes, or individual puppies. The student may physically interact by moving these representations, observe them from different angles, make guesses and estimates, and compare between different number magnitudes and representations.

Prototype 3: Nonstandard Measurement
In this prototype, children are asked to measure a specific distance (ex: of 3 units) by using nonstandard measures - in this case, making a puppy travel by laying out a trail of paper 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, and the puppy becomes unhappy.

Prototype 4: Objects as Fractions
The student can place an arbitrary physical object within a paper number line (which spans from 0 to 1). 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.

Prototype 5: AR Number Blocks
The student can piece together a number of physical blocks, and then use the AR application to count them. If the child groups multiple types of blocks (ex, 4 green blocks and 3 yellow blocks), then the application detects the group and calculates the sum. This can be used as a way of physically solving number problems.

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 our 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. Our augmented reality prototypes touched on the topics of measurement, vocabulary, word problems, fractions, number lines, number representations, operations, counting and cardinality. With the exceptions of the fractions prototype, 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: There was some degree of confusion and frustration early in the process, since 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. However, our process was effective overall, as it helped to identify AR application ideas that teachers were enthusiastic about, and it helped to identify concrete design ideas for how the AR prototypes can be turned into engaging classroom games.

Hi-Fi Prototypes Will Create Tunnel Vision: By first understanding teacher needs, and then designing high-fidelity interactive prototypes that speak to those needs, we were able to create a common ground between teachers and
technology designers. The high fidelity prototypes we created were needed to properly illustrate the high degree of physical interactivity in AR applications, and were much more effective than our initial approach of asking teacher feedback on low-fidelity prototypes. However, when exposed to high-fidelity prototypes, teachers 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:* Teachers did identify new ideas for AR games, or novel approaches for how an AR application may be used in the classroom. 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 of course children, in order to ensure the content and interaction mechanics are effectively addressing the curriculum needs.

**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 analyze 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.

The authors would like to thank PBS KIDS for supporting this research. The authors would also like to thank Sara Atienza and Danielle Brown from WestEd, for their assistance in the research studies. The current research was conducted as part of the Ready To Learn Initiative developed by the Corporation for Public Broadcasting (CPB) and the Public Broadcasting Service (PBS) with funding from the U.S. Department of Education.¹

**References**

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.