Augmented Reality (AR) Exploratory Study to Support the Development of PBS KIDS AR Games

A Report to the CPB-PBS Ready To Learn Initiative

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WestEd conducted an exploratory mixed-methods study for the CPB-PBS Ready To Learn Initiative to better understand how AR games might be incorporated into early elementary classroom instruction and to provide feedback to the Corporation for Public Broadcasting (CPB) and PBS about potential educational benefits and drawbacks of AR technology for students 6 to 8 years old so that PBS can improve future development. Researchers evaluated the learning potential of two augmented reality games which focus on basic arithmetic skills for early elementary children: *Fetch! Lunch Rush*, developed by the Public Broadcasting Service (PBS) for the CPB-PBS Ready To Learn Initiative, and *Monster Plus*, a game developed by the Georgia Institute of Technology. Overall study findings are highlighted below.

- On average, there was a small gain in student performance on a math assessment from pre-test to post-test, but this gain was not statistically significant. Student performance on the assessment was quite variable.

- As currently designed, teachers would primarily use these AR games to help students improve their speed and accuracy with existing math skills or as supplements to whole-class lessons rather than stand-alone teaching tools.

- Providing more in-game instruction and support for students would enhance the utility of the AR games in classroom environments and increase their learning potential. In-game instruction and support could include more frequent hints, the ability to adjust game difficulty, and tutorials to help students learn new skills and problem-solving strategies.

- Students experienced significant usability issues that may have interfered with their ability to learn from the games. Problems included difficulty holding and manipulating the devices as well as problems with the AR technology itself.

- AR technology has great potential for increasing students’ motivation and engagement in the classroom, not just by providing more interesting learning activities, but also by piquing students’ interest in the technology itself.

- AR technology can help teachers meet the needs of diverse learners by allowing children to engage in physical activity and use their tactile sense, and by providing more introverted children a safe, private place to make and learn from mistakes.
• A particular strength of AR might be to provide teachers with many sets of virtual manipulatives, which would be more concrete and reality-based than purely digital objects but also do not have the cost and storage requirements associated with physical manipulatives.

• Teachers expressed concern about not having access to certain types of technology needed to use AR in their classrooms and that substantial time and training would be needed in order to use AR effectively in traditional classroom settings.
Executive Summary

Introduction

Augmented reality (AR) technology is being increasingly used in a wide variety of contexts, including advertising and information technology. In augmented reality, a live camera feed of the real world is combined with digital images and text to create an enhanced and often interactive experience for the user.

The Corporation for Public Broadcasting (CPB) and the Public Broadcasting Service (PBS) have been exploring possible uses of AR technology in educational games for children 6-8 years old as part of the CPB-PBS Ready To Learn Initiative. Funded by the U.S. Department of Education, the CPB-PBS Ready To Learn Initiative supports the development of educational television and digital media targeted at preschool and early elementary school children and their families. Most AR applications in existence have been developed for adults or older children; PBS is breaking new ground with this initiative to develop educational AR games for young children.

In this study, researchers evaluated the learning potential of two augmented reality games which focus on basic arithmetic skills for early elementary children: Fetch! Lunch Rush, developed by PBS for the CPB-PBS Ready To Learn Initiative, and Monster Plus, a game developed by Georgia Institute of Technology. The goal of this study was to better understand how AR math games might be incorporated into early elementary classroom instruction in order to help CPB and PBS direct future development efforts. This study is a part of broader formative evaluation of the CPB-PBS Ready To Learn Initiative to provide CPB and PBS with information, insights, and recommendations on the use of digital media in early childhood and elementary educational settings.

Research Design

This was an exploratory study, designed to identify areas of promise and potential pitfalls when trying to incorporate AR math games into classroom instruction. The study addressed two primary research questions:

1. Can children learn the targeted math skills in an AR experience?
2. What added value could AR technology bring to classroom settings?

To answer these questions, researchers designed a mixed-methods study that incorporated student math assessments and qualitative instruments such as classroom observation and interview protocols.

Researchers collected data from 15 students (9 boys, 6 girls) attending an out-of-school-time (OST) program in the San Francisco Bay Area during the summer of 2012. This OST program is located in a high priority/underserved community. The majority of students are Hispanic, with some classified as English language learners. The program focuses on providing academic, social, and athletic programs for at-risk students ages 6-18 years old. All students participating in this study were rising second graders between the ages of 7 and 8 years old.
In addition, two teachers unaffiliated with the OST program agreed to be interviewed for the study. One teacher was in her second year of working with children in grades 1-3 at a private school; the other teacher was an experienced math coach who has focused on kindergarten and early elementary students in public and charter schools.

Data from observation protocols were analyzed using descriptive statistics such as frequencies and ranges, in order to develop an overall narrative of what happened during the game-play sessions. Teacher interviews, student focus group sessions, and researcher debriefs were transcribed and coded using the HyperResearch software program. Coded transcripts were analyzed for themes that informed the answers to each relevant research question.

Researchers analyzed student performance on the math assessments, which tested students’ speed and accuracy on addition and subtraction, using descriptive and non-parametric inferential statistics to see whether students improved in either speed or accuracy from pre-test to post-test.

Results

Several key findings emerge from both the quantitative and qualitative data analyses and suggest the following conclusions with respect to the primary research questions:

Can students learn the targeted math skills in an AR environment?

A small but not statistically significant gain in mean pre-test to post-test performance suggests students can learn the targeted math skills in an AR experience; however, in this study they did not do so consistently. Factors that may have impeded student learning include:

- Students needed more frequent hints and the ability to adjust difficulty.
- As currently designed, the games do not provide sufficient instruction and support for students to learn new math skills.
- Students experienced significant usability issues that may have interfered with their ability to learn from the games. Problems included difficulty holding and manipulating the devices as well as problems with the AR technology itself.

What added value could AR technology bring to classroom settings?

- Teachers would primarily use the tested games to help students improve their speed and accuracy with existing arithmetic skills or as supplements to whole-class lessons rather than stand-alone teaching tools.
- AR technology has great potential for increasing students’ motivation and engagement in the classroom, not just by providing more interesting learning activities, but also by piquing students’ interest in the technology itself.
- AR technology can help teachers meet the needs of diverse learners by allowing children to engage in physical activity and use their tactile sense, and by providing more introverted children a safe, private place to make and learn from mistakes.
• A particular strength of AR might be in providing teachers with many sets of virtual manipulatives, which would be more concrete and reality-based than purely digital objects but without the cost and storage requirements associated with physical manipulatives.

• Teachers expressed concern about not having access to certain types of technology needed to use AR in their classrooms and that substantial time and training would be needed in order to use AR effectively in traditional classroom settings.

Conclusions and Recommendations

Given the findings of this study, we offer the following recommendations for future development of AR technology in order to maximize its math learning potential:

• Provide a way for teachers to differentiate instruction or for students to self-select appropriate levels. Alternatively, program the game to adapt to a student’s level based on his or her performance in the game, making for a much more individualized experience.

• Program games to instruct students on new math skills and problem-solving strategies, or develop whole-class lesson plans that a teacher can use with the AR games; PBS has developed some lesson plans for its current PBS KIDS computer math games that could be used as models.

• Make sure the technology works smoothly and accurately so that technical problems do not interfere with students’ ability to learn from the game. Thoroughly user-test AR applications with both student and teacher populations.

  » Make sure the game requirements are appropriate for the developmental level of children in the target age group. Consult instructional designers and conduct user-testing to ensure the academic content is targeted at the correct level, that children can clearly see and correctly interpret what they see on the screen, and that children can physically hold and manipulate the device for the duration of the game.

  » Ensure hints and other scaffolding in the game are sufficient for students to play the game without having to ask an adult for help.

  » Verify that time, equipment, and space requirements are appropriate for classroom implementation and accessible to teachers. In particular, understand the concerns teachers have with access to and maintenance of technology and either design around them (e.g., by creating a game that can be played with the device laid flat on the table or held in a stand) or provide suggestions for mitigating them (e.g., recommendations for protective cases).

• Provide training materials for teachers to help them understand how to use the technology and integrate it effectively into the classroom. Determine when, for how long, and how often students should play the game before they will show improvement in the target skills.

• Use the AR in a way such that it is clearly advantageous over traditional paper-and-pencil or purely computer-based math instruction.
Augmented reality (AR) technology is being increasingly used in a wide variety of contexts, including advertising and information technology. In augmented reality, a live camera feed of the real world is combined with digital images and text to create an enhanced and often interactive experience for the user. An early example of AR technology appears often on live TV broadcasts of football games: the yellow first-down line that is digitally inserted into the live video feed. Other examples of AR technology include smartphone mapping and tourist applications, in which route or landmark information is overlaid on top of the video feed from the phone’s camera.

The Corporation for Public Broadcasting (CPB) and the Public Broadcasting Service (PBS) have been exploring possible uses of AR technology in educational games for children 6-8 years old as part of the CPB-PBS Ready To Learn Initiative. Funded by the U.S. Department of Education, the CPB-PBS Ready To Learn Initiative supports the development of educational television and digital media targeted at preschool and early elementary school children and their families. Most AR applications in existence have been developed for adults or older children; PBS is breaking new ground with this initiative to develop educational AR games for young children. The goal of this study was to better understand how AR math games might be incorporated into early elementary classroom instruction in order to help CPB and PBS direct future development efforts. This study is a part of broader formative evaluation of the CPB-PBS Ready To Learn Initiative to provide CPB and PBS with information, insights, and recommendations on the use of digital media in early childhood and elementary educational settings.
This study focused on two AR math games that help students practice addition: Monster Plus and Fetch! Lunch Rush. Both games are marker-based games for the iPhone or iPod Touch.1 In marker-based games, users print out paper game pieces, or markers, which contain images that the iPhone app is programmed to recognize. The user views the marker with the iPhone’s camera (see Figure 1). When the iPhone app recognizes the marker, it triggers game actions.

### Monster Plus

Monster Plus is a marker-based AR math game about addition developed by the Georgia Institute of Technology. At the time of testing, the game was still under development.

The game uses a large marker depicting an island with boat docks and nine smaller markers which represent boats (Figure 2a). In this game, a hungry monster lives on the island. Students view the island marker using the phone camera to see how many food items the monster wants to eat (shown in the top left corner of Figure 2b). Each boat marker is carrying the number of food items shown on the marker, from 1-9—there is one boat marker for each number. To solve the problem, the student needs to choose a combination of boat markers that add up to the correct number of food items and physically place those boat markers in the docks on the island marker. When students view the docked markers through the phone camera, the game will total up the amount of food that has been brought to the island (shown at the bottom of Figure 2b). If the amount of food is correct, the monster will eat the food and the next problem begins.

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1 At the time of this report, the games were not available for non-iOS mobile devices.
Students progress through several levels of difficulty in Monster Plus. When students begin the game, the monster requests single-digit amounts of food—students can solve the problem with only one boat. Students then progress to numbers that require at least two boats to solve (e.g., 12 or 14 food items), and then numbers that require three boats (e.g., 18 or 20 food items). The fact that students only have one boat for each digit 1-9 adds some difficulty to the game. For example, students cannot dock two boats carrying five items each to give the monster 10 food items—they must find two boats carrying different numbers of items that add up to ten.

The version of Monster Plus tested did not have a definitive end. Students continued to receive new problems until they chose to stop playing the game.

Fetch! Lunch Rush

Fetch! Lunch Rush is an AR game about addition and subtraction for 1-4 players, developed by PBS for the CPB-PBS Ready To Learn Initiative. The game is free and available for iPhone and iPod Touch and can be downloaded from the Apple App Store.²

In the game, students solve addition problems in order to help Ruff Ruffman put the correct number of sushi pieces into a lunch order for each member of his movie crew. There are ten markers that need to be printed for this game—the app will prompt users to download a pdf of the markers from the PBS KIDS website. Each of the markers is labeled with a number from 1-10 (Figure 3), which indicates how many sushi pieces will appear in the game when the marker is viewed with the phone camera (Figure 4). Students can play with the markers spread out on a desk, or an adult can tape them around a classroom.

Figure 3. Markers for Fetch! Lunch Rush. Image source: PBS KIDS

Each game consists of five rounds of three problems each. For each problem, an equation appears at the top of the screen along with a timer.³ Students must find the marker containing the number that makes the equation true and view it with the camera. This makes the sushi appear on the iPhone screen. If students answer the problem correctly, they move onto the next problem. If students “miss” a problem, they are given a hint and another opportunity to solve the problem. At the end of each round, the game shows the students the number of “misses” for that round and the total time to complete the round.

The game progresses through a series of difficulty levels. Students who have never played the game before will begin on the easiest level, Level 1: Gofer, where they see only simple single-digit addition problems. As students master solving the problems presented, the game automatically increases the difficulty until students reach Level 10: Top Dog. The harder levels gradually introduce larger

³ Students do not have to solve the problem within a time limit.
numbers, more algebra-like problems with the unknowns on the left side of the equal sign, as well as subtraction (see Table 1). Students can tap the help button at the top left corner of the screen to get a hint. The software will save the students’ progress at the end of each game so that students who come back to play a new game will begin where they left off in terms of difficulty. The mastery criteria for the game is designed such that students must play through the entire game at least four times in order to reach the highest level of difficulty.

If there are multiple players, the student who answers the most problems correctly wins the round—the student who wins the most rounds wins the game. In multiplayer mode, the total time needed to complete the round is used as a tiebreaker—the fastest student will win the round.

Table 1. Levels of Fetch! Lunch Rush

<table>
<thead>
<tr>
<th>Level</th>
<th>Level Name</th>
<th>Example Problems</th>
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<tbody>
<tr>
<td>1</td>
<td>Gofer</td>
<td>(3 + 1 = ?) (6 + 2 = ?)</td>
</tr>
<tr>
<td>2</td>
<td>Snack Weasel</td>
<td>(2 + ? = 8) (4 + ? = 9)</td>
</tr>
<tr>
<td>3</td>
<td>Scouting Pigeon</td>
<td>(4 - 1 = ?) (10 - 2 = ?)</td>
</tr>
<tr>
<td>4</td>
<td>Wardrobe Wiz</td>
<td>(8 - ? = 7) (5 - ? = 3)</td>
</tr>
<tr>
<td>5</td>
<td>Animal Wrangler</td>
<td>(? + 1 = 2) (? + 4 = 3)</td>
</tr>
<tr>
<td>6</td>
<td>Head of Hair</td>
<td>(? - 1 = 5) (? - 2 = 8)</td>
</tr>
<tr>
<td>7</td>
<td>Music Maestro</td>
<td>(5 + ? = 15) (? + ? = 11)</td>
</tr>
<tr>
<td>8</td>
<td>Stunt Monkey</td>
<td>(? + 17 = 18) (15 + ? = 20)</td>
</tr>
<tr>
<td>9</td>
<td>Cool Cat</td>
<td>(18 - 8 = ?) (19 - 11 = ?)</td>
</tr>
<tr>
<td>10</td>
<td>Top Dog</td>
<td>(15 - ? = 10) (? - 9 = ?)</td>
</tr>
</tbody>
</table>
This was an exploratory study, designed to identify areas of promise and potential pitfalls when trying to incorporate AR games into classroom instruction. The study addressed two primary research questions:

1. Can children learn the targeted math skills in an AR experience?
2. What added value could AR technology bring to classroom settings?

To answer these questions, researchers designed a mixed-methods study that incorporated student assessments and qualitative instruments such as classroom observation and interview protocols. Detailed information about these measures appears in the following section.

Researchers collected data from 15 students (9 boys, 6 girls) attending an out-of-school-time (OST) program in the San Francisco Bay Area during the summer of 2012. This OST program is located in a high priority/underserved community. The majority of students are Hispanic, with some classified as English language learners. The program focuses on providing academic, social, and athletic programs for at-risk students ages 6-18 years old. All students participating in this study were rising second graders between the ages of 7 and 8 years old.

Students participating in the study were pulled from general recreation activities for one hour on each of three consecutive afternoons in order to play the games. Researchers began each session by describing the schedule for the afternoon and reminding students that their participation and feedback was important and appreciated. In all cases, students were allowed to play the games for as long as they liked.

In addition, two teachers unaffiliated with the OST program agreed to review and play the games and be interviewed for the study. One teacher was in her second year of working with children in grades 1-3 at a private school; the other teacher was an experienced math coach who has focused on kindergarten and early elementary students in public and charter schools.

Measures

Qualitative Instruments

Researchers developed a classroom observation protocol and a semi-structured teacher interview protocol in order to supplement and provide context for the assessment data. On the classroom observation protocol, researchers recorded minute-by-minute details of each play session, including the number of students, the length of play, and specific issues related to engagement, content (e.g., a child doesn’t know how to solve the math problem), or usability of the technology. Students also participated in focus group sessions about their experiences with the games. Following each classroom observation, researchers conducted a separate debrief session in which they described their observations as well as students’ reactions to and struggles with the games. The teacher
interview protocol focused on the appropriateness of the content for the target grade level, feasibility of classroom use, and suggested modifications and supports. The participating teachers did not participate in the classroom observations, but were given as much time as they wanted to explore Fetch! Lunch Rush and Monster Plus before the interview began.

**Student Assessment**

Researchers developed a single assessment to be administered before and after students had played both games. This assessment consisted of three sections which closely aligned with the content of the games: 1) a 3-minute timed addition section with 42 items, 2) a 3-minute timed subtraction section with 48 items, 3) an untimed multiple choice and short-answer constructed-response section which included five researcher-developed items and three items from the California Standards Test (CST).

The timed addition and subtraction sections were designed to have significantly more items than the average student could solve—this lets researchers measure the full range of students’ performance, including those who perform well above grade level. In the timed sections, students solved problems with the unknown on both the left and right sides of the equation, as they do in Fetch! Lunch Rush (e.g., 4 + 1 = ___ and 5 + ___ = 8). All problems in the timed sections used only whole numbers from 0-10.

**Procedure**

Students participating in the study were pulled from general recreation activities for one hour on each of three consecutive afternoons in order to play the games. Researchers began each session by describing the schedule for the afternoon and reminding students that their participation and feedback was important and appreciated. In all cases, students were allowed to play the games for as long as they liked.

On Day 1, students were briefed on the purpose of the study and given the pre-assessment as described above. Students were then paired into groups of two at different stations in the computer lab to play Monster Plus. Researchers were available to assist with technical or instructional difficulties, while also recording observations such as time spent on particular levels of the game, the overall level of student engagement, and the potential for use of the game in a standard classroom. At the end of the session, students shared their reactions to the game and the technology in a short debrief.

The activity for Day 2 required splitting students into groups of 4-6 students each. One group at a time was invited to play Fetch! Lunch Rush in the OST program’s dance studio, a more open space that facilitated the placement of the various markers while allowing the students more room to move around. Each student was given his/her own device and began the game on the first and easiest level. Students were asked to check in with a researcher each time they progressed through a level, so that their time spent on each level and the number of answer attempts could be recorded. Every student played the game with their assigned group of students, with some students volunteering to play the game a second time with another group. While students were waiting to access the dance studio, they were given the opportunity to play a computer game of their choice on the PBS KIDS GO! website.
Day 3 began with a brief review of what games the students had played. Students were asked to describe the different features of each game and to give examples of the types of problems that they had to solve. Students were then given the post test before regrouping for a final debrief. During this session they were asked to describe their reactions to Fetch! Lunch Rush, as well as compare their experiences with each game.
Observation protocols were analyzed using descriptive statistics such as frequencies and ranges, in order to develop an overall narrative of what happened during the game-play sessions. Teacher interviews, student focus group sessions, and researcher debriefs were transcribed and coded using the HyperResearch software program. Coded transcripts were analyzed for themes that informed the answers to each relevant research question.

**Game-Play Observations**

Two students who participated in Day 1 of the study were absent for Day 2 (one boy, one girl). Participating students played *Monster Plus* for 10-20 minutes and *Fetch! Lunch Rush* for 9-14 minutes, with individual students completing each round in 30-90 seconds. Several students did not complete a full game of *Fetch! Lunch Rush*, which means they played fewer than five rounds (15 problems). For both games, researchers ended the session when students’ interest in the game waned. Thus, the times above likely indicate the maximum amount of time a teacher should allot for a single session of free gameplay. Summaries of findings from the classroom observations, including the student and researcher debriefs, follow.

**Engagement**

Observation data show that students were highly engaged in playing both *Monster Plus* and *Fetch! Lunch Rush*. For both games, students expressed verbal excitement to themselves, friends, or the classroom in general for almost every minute of game play. In general, students were excited to share their iPhone screens with peers and researchers in the room. There was significant “collaborative talking” that took place during game play, as students would help each other if they heard other students were experiencing a difficulty they had already overcome.

In particular, students playing *Fetch! Lunch Rush* were often willing to help each other complete the game—there were many instances of students sharing verbal hints or clues with each other. In contrast, researchers noted that it was difficult to support multi-player activity in small groups with only one device, as was the case for *Monster Plus*. There was some turn-taking, but it appeared that the child who held the iPhone at a particular moment was the one more engaged.

Some students became bored or frustrated with the games towards the end of a session or if they experienced technical difficulties. During a *Monster Plus* focus group session with the students, one student mentioned he would prefer to play the game on a computer.

**Math Content**

Data from the classroom observations showed that students often were not able to solve the math problems in *Fetch! Lunch Rush* and *Monster Plus* independently. Students often asked researchers content-related questions and requested assistance with solving math problems. The amount of
support needed varied by session and by student; in some cases, researchers were only asked one question at the beginning of the play session, while in other cases, researchers answered questions for over half of the session.

Monster Plus does not keep records of student performance in the game so researchers were unable to collect reliable data on how many problems were completed and how students progressed in the game. Students spent most of their time with Fetch! Lunch Rush playing in Level 1: Gofer and Level 2: Snack Weasel, which both focus on addition. Subtraction is introduced in Level 3: Scouting Pigeon, which means that some students may not have had practice with subtraction during the study (Monster Plus does not require subtraction).

Usability

Observation data show the user experience for Fetch! Lunch Rush was fairly smooth, with only a few students asking questions related to game directions or the user interface. When students had questions, they tended to ask them within the first few minutes of the session and then did not ask any further questions as the session progressed. Technical problems with the Monster Plus app were more extensive, which might be expected as the game was still under development—occasionally the game lost track of the main island marker or otherwise failed to render or register all the objects correctly, a problem that could affect the game’s scoring of students’ responses. About half of the students who played Monster Plus had only minor technical difficulties with the game that could be resolved within a few minutes. However, the other half of the students encountered difficulties with the hardware and app that persisted throughout the majority of the game play session.

A major usability problem with Monster Plus was the small size of the iPhone screen. Students often struggled to see the game characters’ actions and count the objects on the screen, particularly if more than one child was trying to view the screen at a time. Students also had difficulty manipulating the iPhone. During a focus group, one child mentioned that fingers often got in the way while holding the iPhone, making it difficult to see items on the small screen. The children also noted that after a while the iPhone became too heavy to hold up. So while switching to a larger device like an iPad would help with the problems related to the smallness of the iPhone, it would exacerbate the problems related to device weight.

Teacher Interviews

Analysis of the teacher interviews identified several major themes which will be explored further in the following sections: 1) in-game instruction and support for students, 2) addressing the needs of diverse learners, 3) engagement, 4) barriers to widespread adoption of AR technology in classrooms, and 5) concerns about usability for students.

In-Game Instruction and Support for Students

Teachers felt that the games tested were more appropriate for helping students practice math skills they had already learned rather than as stand-alone teaching tools for teaching new math skills. Teachers were more positive about Fetch! Lunch Rush. They appreciated the in-game scaffolding and stated that the game was appropriate for first and second grade students. As one teacher noted, “I thought they had really good descriptions, with the voice, the instruction.” This teacher also appreciated the fact that the pieces of sushi were displayed in groups of 5, saying, “a 10-frame… awesome…that is very Common Core. That is perfect for 1st [grade]."
Both teachers felt that more scaffolding, more audio and visual prompts, and better-defined levels of difficulty geared toward different age groups and through which students could progress would make these games more appropriate as teaching tools.

I think I would use it more in terms of reinforcement . . . I would probably teach a whole class lesson in that, and if some of the kids were struggling, give them Fetch! and be like, here, try it again. That kind of thing. Use it as a support versus a learning tool.

...I think they could [add more in-game instruction] if they wanted to make it a teaching tool. Have Fetch! give them instructions and a couple of examples of what they’re going to do. Have him show them how to make the sushi order in each level. Then give them a couple to try. So have him demonstrate and then give it to the kids to try . . . I think that in terms of using it as a support, a lot of my students could have used it. When they were struggling [in the past] with the missing number, the only technology I had to give to them was a worksheet. So I didn’t have any iPad-computer to give to them and say, try it this way, in a different modality and see if that helped. So Fetch! could definitely be a really cool way of not giving them another worksheet, giving them something else to try.

Both teachers interviewed mentioned that “it would be great if” and offered several suggestions for ways to modify the games, such as having students select starting levels of varying difficulty in Fetch! Lunch Rush, or including subtraction problems or second and third addends in Monster Plus. One teacher noted that she wished the timer in Fetch! Lunch Rush was optional, so that she could have students either explore the classroom looking for the markers without running, or cluster around a set of markers on one table and compete in a time trial.

Addressing the Needs of Diverse Learners

AR-enhanced learning has the ability to meet the needs of diverse learners. According to one teacher, more creative-minded students would most likely do well in an augmented reality setting compared to simply working with paper and pencil.

I think it depends on their learning style. I think some of the students are a lot more comfortable with a worksheet. So just very worksheet minded, I guess, and some of them are more creative minded, and would really enjoy Fetch! I think it would be determining which kid needed what, and then giving them that to best support their learning.

It widens my ability to teach, I think. The goal in all teachers’ classrooms is to provide for every type of learner you have. Kinesthetic, and visual, and auditory—all those learners exist. But you can’t always do a visual thing, and auditory things, and a hands-on thing for every single lesson. Time does not exist in the day for that to happen. And this [augmented reality] combines a lot of them. The kids are seeing, the kids are hearing, the kids are touching . . . And it touches all of the learner categories versus a book and a worksheet, or you know, a hands-on activity. That gets some of them going, but not all of them.

In particular, the teachers appreciated that Fetch! promoted physical activity. This was especially important in one school that did not have a physical education teacher during the year of the testing.

But Fetch!, you can put like—my favorite thing during this year was hiding stuff in my classroom, and seeing them find it. That was like the greatest experience. They were like, where did you put it? And the fact that they all have to run around and get their bodies moving and
stuff, because we didn’t have PE teachers this year. So it was kind of like finding ways for them to get their bodies moving was huge. And that would be so fun.

I like having to manipulate something as well, rather than just run around with the phone, or touch the phone. I like the fact, especially for young children, to actually move something. Because that really engages them in another way.

The teachers appreciated that AR enables students to engage their tactile sense—students may find it more engaging than sitting in front of a computer and clicking with a mouse. The fact that AR allows students to directly manipulate objects was seen as a strength.

A lot of people, teachers, will go to the technology only because it’s neater than the manipulatives. And I don’t really go for that, because then . . . you’ve lost that engagement. It’s more passive. But because the augmented reality engages the environment, it’s not passive anymore . . . So that’s why it’s engaging. If it was just on a computer screen, then I would say, you know, I’d rather have the kids use the base 10 blocks.

On a different note, the teachers also mentioned that educational games on a smartphone could be used to create safe, private spaces for students to make mistakes and learn from them—not all students are equally comfortable in whole-class or collaborative learning settings.

This is more private. If I make a mistake with this, it’s just me and this little iPhone. It’s okay. It doesn’t care. Right? Where it’s not in front of everybody and it’s not this flashcard thing and it’s not this computer game where often the speed [is key]. But I think that the advantage of this is that it gives me some privacy to do my own thinking, whereas other applications may involve too many other people.

Although this particular point applies to smartphone games that don’t incorporate AR, it still represents a way that AR games like the ones tested for this study could help teachers address the needs of many different learners.

Engagement and Motivation

The teachers believed AR technology could increase engagement in the classroom, both because the technology itself is interesting and because the technology enables more engaging ways of learning. As one teacher noted, “I think the kids would think it was so cool, and I’d be like the coolest teacher ever for showing this.” The teachers felt the augmented reality enhanced the environment more than a static desktop/iPad version of a game where the sought-after items are already located on the screen.

One teacher saw the potential in encouraging students to start to question, “how did they do that?” with regard to the technology.

Like I said before, it gets them thinking about how did they make this work? Like how does the sushi get there? And how does the monster get there? And that kind of—I wouldn’t be able to answer their questions about it, but they could, you know, do further research on it and find out how it works, the mechanics of it and that kind of thing.

This could also possibly enhance the children’s interest in science and technology and get them thinking beyond the mathematics in the game to start considering how the technology works. This
finding is consistent with results from WestEd’s 2011 pilot study of Fetch! Lunch Rush (McCarthy, Tiu, Atienza, Yumol, & Banes, 2011).

Barriers to Widespread Adoption of AR Technology in the Classroom

The teachers identified both access and the cost of maintenance as significant barriers to widespread adoption of AR technology in the classroom. Few teachers would have a bank of iPhones, iPod Touches, or iPads at their schools necessary for AR games. One teacher noted that she only had access to a laptop cart one day a week in her classroom, and had to compete with other teachers in her school even for that amount of time. She had tried requesting other equipment such as a document camera, but was rebuffed. This teacher commented that even if she were able to get a set of iPhones or other mobile devices for her classroom, she would be concerned about her students using them, as schools may not have the resources to adequately maintain the devices or support replacement costs for broken devices:

> My kids are so clumsy. Like dropping the phone, you know, phones falling everywhere, getting the phones back from them with fingerprints all over...I didn’t use anything [of my own] after about week 2 because I was getting it back totally trashed...teaching them to be careful with the technology is a big thing. Because they’ll be like, oh cool, an iPhone! Splat. And it would fall off the desk, drop it on the desk, whatever it is. Then they’re screwed. And then I’m out a set of iPhones.4

The teachers also expressed concerns about the time and resources required to learn to use new technology in the classroom.

> It’s time. Because you have to learn it. Time. And also access. For the past three years I’ve been trying to use [an interactive] whiteboard, just to practice on it. But I have no iPad, no access...so I’ve never [been able] to develop my own stuff. So that’s kind of tough...I know that teachers that get [technology tools], oftentimes they don’t get very much training. And it’s only the ones that are really dedicated that spend a hundred years every night learning how to do it.

Setting up the games is also quite time- and resource-intensive. If teachers wish to take advantage of a movement-oriented game like Fetch! Lunch Rush, they must find a space large enough for the students to move around in. Such an active game also requires heightened teacher involvement in order to manage the class and steer the lesson forward. Because of these constraints, the teachers felt that it would be less time-consuming to use more conventional methods of teaching and would not use games like Fetch! Lunch Rush and Monster Plus in their current form.

Usability of AR for Children

The teachers expressed concerns about usability of the AR math games for students. They were worried that students would have difficulty seeing the numbers and other objects on the screen. One teacher identified several specific problems with how the iPhone, island marker, and boat markers in Monster Plus worked together, and also expressed concerns with how the food objects were displayed in the boats:

4 Researchers experienced one instance of the iPhone being dropped during a Fetch! Lunch Rush play-testing session.
The bananas in the boat, because they come up vertically, you really can’t count them at all. So if you were trying to figure it out, there’s no way to count it, and you can’t see it… I could see that this could be very, very confusing.

The teachers expressed another concern about very young students’ use of AR:

The fact is that reality is really kind of iffy with a lot of kids. So this could be confusing. And it’s not that I want to stamp out fantasy…I mean it’s a whole new thing of messing with a kid’s view of how the world works, and what’s really there and what isn’t.

WestEd researchers have previously raised this concern with PBS (McCarthy, Kao, & Tiu, 2012). In developing AR for children, it is important to know and understand the worldview of the targeted age of the child. This would help developers determine whether AR would have the potential to destabilize that worldview.
One student did not take the post-test. This student, along with the two students who did not participate on Day 2, were excluded from the assessment analysis. Thus the assessment results are based on the 12 students (8 boys and 4 girls) who participated in all parts of the study. For the timed sections of the assessment, students received a score that matched the total number of problems solved correctly in that section. Students received one point for each item solved correctly in the untimed section. The related-samples Wilcoxon signed-rank test\(^5\) was used to determine whether students’ scores were statistically different on pre-test and post-test.

Assessment Performance

Researchers analyzed the assessment results to see whether students improved either in their accuracy or in their speed on the timed sections of the test.

**Table 2. The lowest and highest number of problems students attempted on timed sections.**

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<thead>
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<th>Pre-test</th>
<th>Post-test</th>
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<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Addition (42 problems)</td>
<td>3</td>
<td>41</td>
</tr>
<tr>
<td>Subtraction (48 problems)</td>
<td>4</td>
<td>33</td>
</tr>
</tbody>
</table>

Students achieved a mean score of 40.9 points on pre-test and 43.2 points on post-test. There was wide variation in students’ speed on the first two sections of the assessment, with some students proceeding very slowly and some students attempting all or nearly all the items. Table 2 presents the lowest and highest number of items attempted by students on each test, by section, and Figure 5 presents the mean number of items attempted and solved correctly.

Compared to pre-test performance on the timed sections, on post-test students attempted approximately one additional item in the addition section and two additional items in the subtraction section, but the pre-test and post-test differences were not statistically significant. Students’ accuracy varied widely. Of students who attempted at least six items in a section, or one item every 30 seconds, accuracy on attempted items ranged from 29% to 100%. Mean accuracy on items attempted is shown in Table 3.

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\(^5\) The related-samples Wilcoxon signed rank test does not assume a normal distribution.
The mean difference between pre-test and post-test accuracy on the timed addition section is marginally significant (p = .07), but the mean difference between pre-test and post-test accuracy on the timed subtraction section is not. The difference in accuracy between addition and subtraction is also not statistically significant.

There was no difference in mean performance on the untimed section between pre-test and post-test—students averaged 5.5 items correct out of a possible eight on both tests. There were no statistically significant differences between pre-test and post-test performance neither on the untimed section nor on the assessment as a whole. The variability in student performance on the assessments was very high, and so the mean differences are very small by comparison.

Table 3. Mean accuracy on problems students attempted on timed sections.

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
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<tbody>
<tr>
<td>Addition</td>
<td>83.4%</td>
<td>89.8%</td>
</tr>
<tr>
<td>Subtraction</td>
<td>75.4%</td>
<td>79.1%</td>
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</table>
There are several key findings that emerge from both the quantitative and qualitative data analyses and suggest the following conclusions with respect to the primary research questions:

**Can students learn the targeted skills in an AR environment?**

Although the small, but not statistically significant, gain in mean pre-test to post-test performance suggests students can learn the targeted skills in an AR experience, in this study they did not do so reliably. While the sample size and dosage for the study were small, we can still identify trends in the observations and teacher interviews that indicate the games were not optimized for student learning. The students needed more frequent hints and the ability to adjust difficulty. This would facilitate play for a wider range of age groups (e.g., first graders understand the concept of 2 addends in addition; second graders would better understand the concept of 3 addends).

As currently designed, the math games do not provide sufficient instruction and support for students to learn new math skills—for example, if a student is struggling to solve a problem correctly, the game does not attempt to teach the student a new strategy for solving that problem. Thus teachers would only use games like Fetch! Lunch Rush and Monster Plus to help students improve their speed and accuracy with existing math skills or as supplements to whole-class lessons rather than as stand-alone teaching tools.

In addition, students experienced usability issues that may have interfered with their ability to learn math from the games. Poor usability of educational technology for students interferes with learning in at least two ways: 1) if students have to spend significant time trouble-shooting technical problems or waiting for technical help during a class period, it effectively lowers the amount of time students spend with the academic content of the game during that class period, and 2) technical problems distract students from the content to be learned and, consequently, students devote fewer cognitive resources to learning. Thus, good game usability should be considered a prerequisite to student learning.

**What added value could AR technology bring to classroom settings?**

AR technology has great potential for increasing students’ motivation and engagement in the classroom, not just by providing more interesting learning activities, but also by piquing students’ interest in the technology itself. AR technology can help teachers meet the needs of diverse learners in important ways: 1) allowing children to engage in physical activity and use their tactile sense, and 2) providing more introverted children a safe, private place to make and learn from mistakes. A particular strength of AR might be to provide teachers with many sets of virtual manipulatives, which would be more concrete and reality-based than purely digital objects that are displayed
in abstract form on a computer screen, but also do not have the cost and storage requirements associated with physical manipulatives like blocks (assuming a teacher already has access to mobile devices).

However, teachers did express concern about not having access to certain types of technology and felt that the amount of time needed to learn and set up games like Fetch! Lunch Rush and Monster Plus and relative lack of training for using AR as an instructional tool would prove to be prohibitive for widespread adoption of AR technology in classroom settings.

Limitations of Study Design

In interpreting the findings, it is important to remember the study was not designed to be a rigorous evaluation of the games’ effectiveness in the classroom—the goal was to identify areas of promise and potential pitfalls of using AR technology in classrooms. It is not appropriate to use these findings to make general statements about the educational value of AR—there are many ways to implement AR in educational settings other than marker-based games like those tested here (e.g., Dunleavy, Dede, & Mitchell, 2009; Lindren & Moshell, 2011), or even the educational value of the particular games tested. The sample size was quite small, the total gameplay time was relatively short—substantially less than effective “dosages” suggested by prior research (e.g., NMAP, 2008), and there was no comparison group. Further research would be required to make generalizable claims about the effectiveness of AR in classroom environments.

Recommendations

Given the findings of this study, we offer the following recommendations to the CPB-PBS Ready To Learn Initiative for future development of AR technology in order to maximize the learning potential:

- Provide a way for teachers to differentiate instruction or for students to self-select appropriate levels. Alternatively, program the game to adapt to a student’s level based on his or her performance in the game, making for a much more individualized experience.

- Program games to instruct students on new math skills and problem-solving strategies, or develop whole-class lesson plans that a teacher can use with the AR games; PBS has developed some lesson plans for its current PBS KIDS computer games that could be used as a model.

- Make sure the technology works smoothly and accurately so that technical problems do not interfere with students’ ability to learn from the game. Thoroughly user-test AR applications with both student and teacher populations.

> Make sure the game requirements are appropriate for the developmental level of children in the target age group. Consult instructional designers and conduct user-testing to ensure the academic content is targeted at the correct level, that children can clearly see and correctly interpret what they see on the screen, and that children can physically hold and manipulate the device for the duration of the game.
» Ensure hints and other scaffolding in the game are sufficient for students to play the game without having to ask an adult for help.

» Verify that time, equipment, and space requirements are appropriate for classroom implementation and accessible to teachers. In particular, understand the concerns teachers have with access to and maintenance of technology and either design around them (e.g., by creating a game that can be played with the device laid flat on the table or held in a stand) or provide suggestions for mitigating them (e.g., recommendations for protective cases).

• Provide training materials for teachers to help them understand how to use the technology and integrate it effectively into the classroom. Determine when, how long, and how often students should play the game before they will show improvement in the target skills.

• Use the AR in a way such that it is clearly advantageous over traditional paper-and-pencil or purely computer-based instruction.


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