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Teaching Math to Deaf/Hard-of-Hearing (DHH) Children Using Mobile Games:
Outcomes with Student and Teacher Perspectives

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ABSTRACT

Leveraging the use of mobile devices for education, such as instructional games, is an area of increasing interest for targeted subpopulations of students including those who are deaf/hard-of-hearing (DHH). This paper outlines the perspectives of Deaf Education teachers and DHH children who participated in the GeePerS*Math project. Interviews and surveys provide data from the primary implementation of the technology in an ecologically valid setting. Findings included similar results from both teachers and students with regard to attitudes and transfer of skills within the game to those in traditional curriculum. Unintended outcomes, such as gaining orienteering skills and peer-tutoring, were also noted. The results helped to inform the designers of educational technology with ways to relate with classroom instructors and children when creating advanced mobile applications.

KEYWORDS
Deaf Education, Design Research, Educational Technology, Mobile Games

INTRODUCTION

The interest in leveraging mobile technology for education has been increasing in number and complexity in traditional education, military, and corporate contexts for at least the past decade (e.g., Klopfer, Squire, & Jenkins, 2002; Naismith et. al, 2004). Specifically, leveraging portable smart devices such as phones and tablets for K-12 environments has been of keen interest for instructional technologists and learning scientists (Shelton et. al, 2010). Designers of educational technologies must therefore be cognizant of the students' needs as part of their development process.

The iterative design utilized in this project draws from literature in design research. According to Collins et al. (2004), Anderson & Shattuck (2012) and Palalas et al. (2015), design research methods are well-suited to contextually-based, real-world messy settings in projects that require iterative

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evaluation and revision during the project design lifecycle. Gibbons (2014) specifically addresses the existence of a multitude of variables in design research and the need to define, describe, and record "the research situation, for each new iteration, is as much detail as possible, in the spirit of keeping a lab notebook" (p. 109). One component of design research involves creating a detailed profile of the population and environment in which the design experiment is to be conducted. In this instance, the design research team involved the teachers and students early in the design process of all instructional gameplay components, as well as during post-gameplay. This involvement increased the effectiveness in the way the educational tools were built and facilitated the creation of opportunities for successful implementations within the classroom. Specifically, the students provided valuable insight with regard to the design of the educational games. The students provided direction as to how the design could assist their classmates in achieving the educational goals of the exercise.

The GeePerS*Math game was implemented in a state-level network of schools for the Deaf and Blind. Several elementary schools and several classrooms in each school participated. Communication methods of the students included both ASL and oral methods. The children who participated were in 4th, 5th, and 6th grades. Students were surveyed regarding design elements after playing the games. This research followed the IDLF framework as proposed by Bannan-Ritland (2003), in that data was extracted through a design research method as implemented through educational activity. Through the first phase of the iterative design and development process, the following key questions guided this research:

1. How do teachers and students describe the impact on student attitudes as a result of playing the *GeePerS*Math* game?
2. How do teachers and students describe the impact on student knowledge (mathematics concepts, nature of mathematics, and nature of mathematics) as a result of playing the *GeePerS*Math* game?

This article offers a rich description of the initial implementation aimed at designing, developing and evaluating a global positioning GPS mobile game to help students who are deaf and hard of hearing (DHH) learn mathematics. By working with Deaf Education teachers in an iterative design and development cycle, critical aspects of instructional design were identified and monitored as manifested in the prototype technology. Researchers created a prototype mathematics game for mobile devices equipped with GPS technology called GeePerS*Math: The Logic Machine Rescue. This article presents the results of the implementation of the project in several schools with DHH students. Further, it describes ongoing design work based on the student and teacher evaluation of the mobile game to address the future requirements of educational technology in this particular area of study.

ANALYZING THE GAP

Performance indicators over the last four decades describe a consistent and significant gap in the mathematics achievement of DHH students. While the 2013 National Assessment of Educational Progress reports 74% of 8th grade and 83% of 4th grade U.S. students at or above the "basic level" in mathematics, the most recent achievement data on DHH students show ~20% of 4th and 8th graders scoring above a "basic" level of understanding in problem solving and above a "below basic" level in procedures or computation (NAEP, 2013). These percentages indicate an overwhelming majority of DHH students are performing below their grade level with at least half graduating from high school at a 5th/6th grade level in mathematics (Traxler, 2000). These statistics are supported by Blackorby & Knokey (2006) in a study showing that 30–52% of students with hearing loss score below the 30th percentile for mathematics calculation and by Noorian, Maleki, & Abolhassani (2013) confirm DHH students have significant delays compared to their hearing peers. Factors contributing to these results include difficulties with English and traditionally based instructional practices.

Successful communication and language proficiency are critical to learning and classroom performance, however, DHH students struggle with English vocabulary and structure in both oral and written modes (Barham & Bishop, 1991; Kelly & Mousely, 1989; Singleton & Morgan, 2006). Particularly in mathematics, the frequent use of conditionals, comparisons, negation, and inferences as well as multiple meaning words, often impede the DHH student from understanding mathematical concepts and problems (Kidd & Lamb, 1993; Kidd, Madsen, & Lamb, 1993; Pagliaro, 2006; Noorian, Maleki, & Abolhassani, 2013). In addition, signing these concepts (whether in ASL or an English-based sign system) without awareness or knowledge of mathematics may lead to a mis-representation of the concepts/problems causing further misunderstanding (Ansell & Pagliaro, 2001).

Increases in achievement among hearing students can be associated with instructional approaches that engage them in challenging mathematics problems as recommended by the National Council of Teachers of Mathematics (NCTM, 1989; 1991; 1995; 2000; 2010). However, studies show mathematics instruction within Deaf Education relies heavily on traditional practices of rote learning and procedural understanding with little emphasis on higher order thinking skills and true problem solving (Pagliaro & Kritzer, 2005). The achievement gap between these groups could be a result of improper use of instructional aids or a weakness in teaching (Noorian, Maleki, & Abolhassani, 2013).

Some preliminary work has been conducted with children who are DHH to assess whether the use of technology or gaming devices is a useful addition to the set of teaching strategies employed. Marinagi and Skourlas (2013) developed a web-based system called *Multimedu* that integrates wireless networks and mobile devices into educational scenarios. They found new technologies form an attractive framework for supporting DHH students by increasing interest in daily studies and improving communications between student and teacher. Passig and Eden (2000a) claim virtual reality technology games improved the ability to think flexibly in children who are DHH. Similarly, Adamo-Villani and Wright (2007) reported their experiences in engaging children who are DHH and science educational learning through the use of the Science and Math in an Immersive Learning Environment (SMILE) game. The authors found SMILE is enjoyable and easy to use, and they are currently evaluating the effectiveness of SMILE on learning outcomes for children. Passig and Eden (2000b) reported children who are deaf or hard of hearing improved their inductive reasoning skills by using virtual technology games.

Current investigations of mobile learning are promising, though not prolific. Researchers at MIT and University of Wisconsin Madison among others are working to develop authoring systems to make it easier for non-programmers to build and test their own mobile learning games with general populations of students, though the effectiveness of the implementations of these games has yet to be fully investigated (Shelton et. al, 2010). Multiple studies have found the use of mobile applications in the classroom increases student engagement and improves performance (Garaj, 2010; Al Mosawi & Wali, 2015; Reilly &Shen, 2011). The use of mobile applications with low achieving students is specifically successful at increasing engagement and providing a means to explore and learn independently (Al Mosawi & Wali, 2015). Researchers theorize that embodying scientific and mathematics-related concepts through narrative and physical activity can increase learning outcomes and motivation for students who fall behind their peers. The project described in this paper is part of the effort to test those theories through the implementation of GeePerS*Math.

RESEARCH DESIGN

Project GeePerS*Math was implemented in schools for children who are DHH as well as those who are being mainstreamed in the regular public school system. This strategy enabled project developers to better be able to understand the needs and challenges of implementation in each type of school.

One project school had 420 children from K-grade 6, with 40 children who are deaf or hard of hearing in inclusive settings within the school. This school focuses on oral language. The second school was a school serving approximately 50 children, all of whom are deaf or hard of hearing. This school has a bilingual American Sign Language (ASL)/English language immersion program for children.

Design-based research (DBR) is an approach for researching issues relating to pedagogy and learning effects. The research is performed in a way that does not require comparative experiments, but rather relies on an interactive process of design, development, and implementation. "Design-based research involves defining pedagogical opportunities and outcomes and creating learning environments that seek to address these" (Olive, 2007, p.60). The iterations are performed over a period of time to test, refine, and better understand the pedagogies and contexts in which they are used. Wang and Hannafin (2005) have described DBR as a "systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development and implementation based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories"(p.6). Palalas et. al. (2015) agrees when they define DBR as "continuous iterations of analysis, design, development, enactment and evaluation, leading to refinements, revisions and ultimately improved design that is contextualized in the unique educational setting" (p.59). Within this case, an iteration of DBR was used to help understand the design issues related to mobile game design for DHH children. DBR methods are helpful for understanding the experiences of instructional designers during game design and how that information can enhance future design efforts. In addition, DBR methods were used so the researchers of this project could work within a class-based setting to assist in determining the successes and failures of the design implementation in practice.

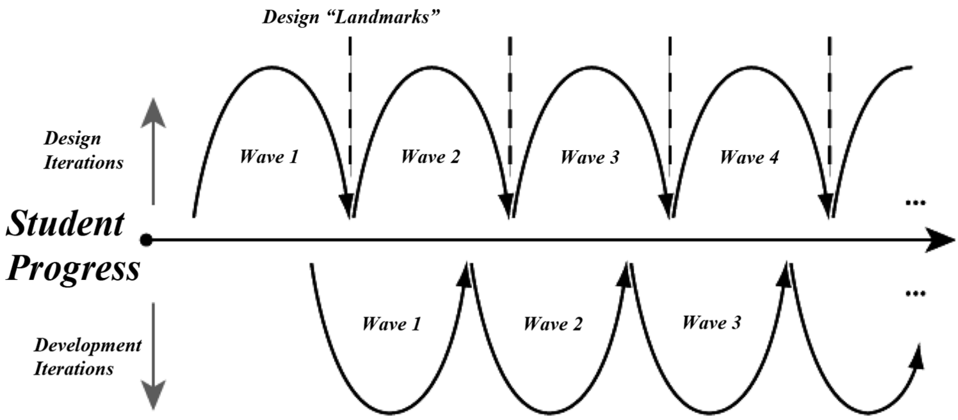
The specific approach used in this project, aligning within the Integrated Learning Design Framework (ILDF), embodies many of the elements within DBR (Reeves et al, 2005; Lewis et al., 2006) in the prescription for studying the design of an instructional game. The approach is grounded in active-learning principles (such as analysis, synthesis and evaluation) and applied to objective-aligned instruction (Barab, et al., 2005; Dede et al., 2004). Bannan-Ritland (2003), in her presentation of the ILDF, drew clear connections between traditional design modalities, e.g., Dick and Carey, (1990) in the way design research combines the creative elements of development with "appropriate adherence to standards of quantitative and qualitative methods in education" (p.21). While the ILDF is meant to provide a program-level perspective based on large-scale interventions, offering a smaller-scale design using this framework can make a significant contribution to informing the design and redesign of educational content-in this case MLBGs, through iterative means. Bannan-Ritland (2003) described four broad phases of design in the IDLF: (a) Informed Exploration, (b) Enactment, (c) Evaluation: Local Impact, and (d) Evaluation: Broader Impact. The approach utilized in this project included components of:

- **Informed exploration:** Literature review, focus group sessions with classroom teachers, case-study development of participating children, and surveys to determine teacher attitudes and beliefs regarding the use of technology in the classroom;
- **Enactment:** The instructional product was designed, produced, and evaluated in the classroom;
- **Local impact:** The instructional product was evaluated in the classroom and iteratively revised throughout the project.

Figure 1 illustrates the iterative process involved in the project development.

Qualitative data was collected and analyzed to inform the evaluation of an initial iteration. To add meaning to data collected and analyzed quantitatively, a multiple-case qualitative research study design was followed throughout the development of this project. Qualitative research is typically used when research is multi-method in its focus, involving an interpretive, naturalistic approach to its subject matter. "This means that qualitative researchers study phenomena in their natural settings,

Figure 1. Iterative process in GeePerS*Math product development (Shelton & Scoresby, 2011)



attempting to make sense of, or interpret, them in terms of the meanings people bring to them." (Denzin &Lincoln, 2011 p.3). Qualitative research is usually applicable when the number of study participants is small and there is high variability in the population (Mertens, 1998). Since this sample population consisted of a low-incidence disability population, the nature of the exploration of the feasibility of this instructional intervention lends itself particularly well to qualitative methodologies, with important but less emphasis on quantitative methodology. The supposition is that given an intervention designed to supplement mathematics knowledge and facilitate practice in the classroom, DHH children will increase their mathematics ability, both in and out of the classroom, resulting in improved achievement of DHH students in mathematics and a decreased gap between DHH and grade level.

Evaluation in the IDLF Primary Iteration Phase: Data Sources and Evidence

Table 1 shows a sample from the mathematics concept chart developed to associate particular mathematics problems and their underlying theoretical structure (Ansell & Pagliaro, 2006).

The *GeePerS*Math* project examined data related to student motivational research which includes both classroom teacher and student perceptions, attitudes, goals, and orientations in a classroom setting for both motivational change and cognitive development. Student data was obtained by observation, surveys, and game performance data recorded by the game itself and stored on the tablets. Table 2 lists the overall study questions in the first column and the second column provides perspective for the overall study rationale.

Table 1. Sample from mathematics concept chart

Problem	Pedagogical Issue
Question: 1 You saw 6 trees at the start of the forest and took the path with 4 more trees. How many trees did you see in all? A: 4 B: 6 C: 10 D: 2 *Answer:* 6 + 4 = 10	Join Result Unknown (JRU) (a number of items are joined by a number of other items) This problem joins 2 values and includes the concept of "more"

Table 2. Study questions, rationale and data sources

Overall Study Questions	Rationale	Data Sources
1. How do teachers and students describe the impact on student attitudes as a result of playing the GeePerS*Math game?	In addition to studying the student and teacher aligned attitudes toward mathematics, the question seeks to understand how teachers and students perceive student attitudes to enhance understanding and view areas of gap.	All teachers and students sampled; Pre-post test data, interviews, Reflection prompts, observations
2. How do teachers and students describe the impact on student knowledge (mathematics concepts, nature of mathematics, and nature of mathematics) as a result of playing the GeePerS*Math game?	The question engages student knowledge toward mathematics (mathematics concepts, process, and nature of mathematics) and the technology as a result of this intervention, and ultimately achievement.	All teachers and students sampled (case study set- Reflection prompts, observations
3. How do teachers and students describe students' mathematics processing skills as enhanced through playing the GeePerS*Math game?	The question seeks to understand how students and teachers describe those mathematics skills through technology, not merely the access influence.	All students sampled (case study set)- Reflection prompts, observation method

METHODS

Participants

Twenty-four children were recruited in the project, with 10 children in 4th grade, 13 in 5th grade, and 1 child in 6th grade. One child in 4th grade was lost as a result of moving out of the school district. The children in the project were behind in math skills, scoring in the average of the 4th percentile on the Math Level Indicator test (Williams, 2003) at the pretest. Table 3 presents student participant demographics.

Student and Teacher Input

Teacher Input

To engage teachers in the development and evaluation of the gaming technology, small focus groups were held with participating teachers in the fall of 2010 and spring of 2011. Questions focused on the development of the gaming technology, as the project staff needed to understand the context in which the children learned, their level of sophistication, attention spans, and how they might perceive the games. Teachers were asked, pre-test/post-test, to rank each child in the study on his or her math skills compared to other children of the same age, how much he or she likes math, values math in life, and can communicate mathematically.

Teachers were asked questions that elicited the types of mathematics problems their children would need to practice in the gaming technology, the types of games and characters necessary to engage children (cartoons, realistic), the game setup, and how the games should proceed. Teachers clearly informed project staff that fantasy adventure cartoon games would engage the children, and games discouraging competition between children would be useful. They were clear in their preferences for games that provided some challenging language, as long as there was the support of ASL signing to assist the children in understanding their tasks. It is important to realize the impact of teacher beliefs when developing partnerships with teachers, as these beliefs will greatly influence their teaching styles and material presented to children. Through our focus group methodology, the research team obtained this information, thus increasing the likelihood of teachers using the gaming technology,

Table 3. Participant demographics

Demographic Variable	Number	Percent
Ethnicity		
White	11	48
Hispanic	9	39
African American/black	0	0
Asian/Pacific	1	4
Native American	2	9
Type of hearing loss		
Sensorineural	19	83
Conductive	3	13
Mixed	1	4
Degree of hearing loss		
Mild	1	4
Moderate	2	9
Moderate to severe	3	13
Severe	7	30
Profound	10	43
Hearing device		
Hearing aid	17	77
Cochlear implant	1	5
Does not apply	4	18

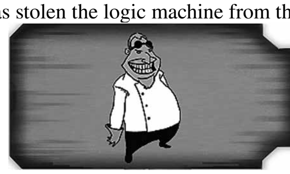
thought it certainly did not ensure efficacy. Table 4 presents the most frequently mentioned ideas from the teachers with regard to the game development.

When the game developers met with the teachers again in the spring to obtain their evaluations of how well the gaming devices matched the teachers' expectations, teachers were pleased that their specifications and expectations had been met, and they enthusiastically noted they were looking forward to using the gaming technology with their children in the fall, as they felt the children would benefit greatly from its use. Figure 2 illustrates screen captures from the GeePerS*Math gameplay.

In interviews following a demonstration of the prototype in spring 2011, teachers offered reflections and analysis on how the game implemented their initial suggestions, and how well it met their expectations. A few of the more impactful examples are provided in the following:

- "The combinations and transposing of written numbers and the number characters… [will be] be highly beneficial."
- "I think the literacy level is very good. I was thinking we would have them learn the skills and the vocabulary—it will help with their literacy and help them apply it to the game. It gives more significance to them because they need to read it." Though text difficulty levels were meant to stay consistent, keeping a focus on *mathematics* learning rather than *literacy*, the levels were deemed helpful and appropriate.
- "I like how you are introducing algebraic expressions with them, (like the word *variable*)—these are concepts they need later."

Table 4. Most mentioned design considerations by teachers of students of DHH

Design Consideration	Game Implementation
1. Use a superhero	 Welcome to the X-Fraction Hero Training Program. There are five stages to your training. In each part you must do a task to get an item and ruin the plans of evil Dr. Ickles and his monsters.
2. Make the mathematics fun; not just mathematics problems	The storyline of the game centers on superhero training. The child using the game is designated as a superhero in training. In the story, Dr. Ickles has stolen the logic machine from the research lab  and the trainee (the child playing the game) must solve a number of challenges (and mathematics problems) in order to progress through the game and rescue the logic machine.
3. Make the mathematics problems straightforward	The river is 26 feet wide. The blue rope is 12 feet long. If you tie the blue and red ropes together, how much more of the red rope do you need to be able to get across the river? A: 14 B: 2 C: 12 D: 10
4. Add pictures and have a sign link as well (signing can be turned on or off)	The project is partnering withVCom3D include a signing avatar that can be turned on or off. This provides additional scaffolding instruction if needed. 
5. Teach the language and the mathematics at the same time (e.g., less than or more than)	The river is 26 feet wide. The blue rope is 12 feet long. If you tie the blue and red ropes together, how much more of the red rope do you need to be able to get across the river? A: 14 B: 2 C: 12 D: 10

continued on following page

Table 4. Continued

Design Consideration	Game Implementation
6. Order of concepts: 1. G1: +/- 2. G2: Rounding/Estimation 3. G3: Measurement 4. G4: Fractions 5. G5:Multiplication/Division	The concepts were ordered according to input from the classroom teachers at the Schools for the Deaf and Blind (SDB).
7. Parent materials and teacher materials should be included	*Materials for teachers:* Includes mathematics questions appropriate for use in the classroom and parallel the mathematics questions in the game. *Materials for parents:* Includes mathematics questions appropriate for use in the home with daily living skills and parallel the mathematics questions in the game.

Figure 2. Screen captures of GeePerS*Math gameplay

- "My expectations have been met." One teacher pointed out that movement is extremely important—"We have kinesthetic learners. I really like that we have them up out of their seats moving. These are perfect things to hit. …I have them learn pronouns using the army marches, and when they are trying to call it back I can see them doing the army marches so they remember it better."
- "This is a really good representation of 4th grade math curriculum. Fifth grade, I would pull in algebraic expressions. Representing the unknown as *X*. Once they understand the concept they'll be able to do it."
- "I like that there are parent materials—it is a way for them to be involved in education."
- "The kids could learn additional skills besides math by playing the game." The game also incorporates orienteering and map-related skills, literacy, translation, problem-solving and exercise.
- "I think the cartoons are perfect. The characters repeat themselves. The pictures are great. It meets the kids' level. They see cartoons—it just fits with their lives."

Additionally, teachers were surveyed after every game. The post-game survey, a 4-point Likert scale, included questions regarding how much the children liked the game, how hard is the game for the children, how much does the teacher like the sign-language in the game, how much does the teacher like the math problems in the game, and how much does the teacher think the children learned from the game. A monthly survey asked open-ended questions regarding the implementation of the games in the classroom including how the teacher incorporates the games into the regular curriculum, how could games be made better to fit into the classroom curriculum, what successes or barriers has the teacher observed in the gameplay, and how does the teacher feel the games have helped or not helped the students learn math.

Student Input

Students were involved in the iterative design and development process via post-gameplay surveys and subsequent revisions of the games. Ames and Archer (1988) stated modifying or changing the nature of student's experiences in the classroom "may provide a viable way of redirecting students' achievement goal orientation" (p. 265). Still, in understanding student goal orientation, there is utility in studying both motivation and cognition simultaneously (Bransford, Brown, & Cocking, 2001).

Students were surveyed (open-ended questions and 4-point Likert scale) both pre and post-test regarding their attitudes about math. Questions included what helps you learn math, what do you like best about math, how good are you in math, how important is math in your life, and how hard is math to you. In addition, students were surveyed (open-ended questions and 4-point Likert scale) after playing each game. These surveys asked students how much fun is the game, how hard is the game, how much do you like the sign language, how much do you like the math problems, how much do you like getting to walk around, and how much did you learn in the game. The responses to the post-game surveys are illustrated in Table 5.

RESULTS: IMPLICATIONS OF INTEGRATING MATH GAMES

Children's Pretest Profiles

The children in the project were behind in math skills, scoring in the average of the 4th percentile on the Math Level Indicator test (reference) at the pretest. Children's strongest math skills were in the addition and subtraction areas, with an average of 81% correct answers. Their performance in multiplication and division (37% correct), fractions (4% correct), algebra (23%) decimals (6% correct), and word problems (21%) demonstrated poor performance, which did not improve over the course of the project, due to the short term of the intervention (December-April).

Children's Feedback Regarding the GPS Games

As part of the GPS project, children played a GPS math game for approximately 40 minutes on various occasions throughout the school year. The goal was children would play the games at least twice

Table 5. Children's responses to GPS math game. Number of children responding is in parentheses. Only half of the children used sign language; the other children did not respond to this question.

Question	Time 1	Time 2	Time 3	Time 4	Time 5
How fun is the GPS math game?	3.85 (20)	3.67 (15)	3.59 (17)	4 (4)	3.75 (4)
How hard is the GPS math game?	2.2 (20)	2.13 (15)	1.82 (17)	2 (4)	1.25 (4)
How much do you like the sign language?	4 (10)	3.44 (10)	3.18 (11)	3.75 (4)	3 (4)
How much do you like the math problems?	3.3 (20)	3.4 (15)	2.94 (17)	3.25 (4)	2.5 (4)
How much do you like getting to walk around?	3.7 (20)	3.71 (15)	3.35 (17)	2.5 (4)	2.75 (4)
How much did you learn in the game?	3.45 (20)	3.6 (15)	3. 18 (17)	3 (4)	2.5 (4)

per month, if not more, but teachers definitely had their students play them at least once per month. Students provided their feedback about the games to help further refine the games. The classroom teacher conducted these surveys by using a white board and signing, if appropriate, to help explain the questions to the children. The children each filled out their own survey form. Table 5 presents information about how the children rated the games each month.

When children were asked how fun the GPS math games the first time they were used, they averaged 3.85 on a 4 point scale, indicating they greatly enjoyed playing the games. When the children were asked how fun they were at the end of the project, they averaged 3.58, indicating continued enjoyment with the games. The children said they liked getting to be outside and moving around, having to try to find the green question mark, the math problems, the sign language, and reading the story and problems. Children thought the math games were somewhat hard at the beginning (2.2 out of 4 point scale), but by the end of the project, they didn't they were quite as hard (1.82). When comparing how much the children felt like they learned math by using the games, the children felt like they learned quite a bit at both times (3.45 the first time they played it, and 3.18 the last time they played it). When asked what they learned, children had a variety of responses, including following directions (north, east, south, west), how to read math problems, how to do math, and how to add, subtract, and multiply. The most powerful comment was stated by a child who said he learned math can be fun, which is very telling of these children's earlier math experiences, and directly targets the objective of the GeePerS*Math project. Several children indicated they were ready to be challenged more and when asked what else they would like to have in the games, they stated they wanted harder math problems to challenge them more.

As can be seen in Table 5, the GPS math games have great potential for students, as they think they are quite fun, although they are a little hard for children to complete. However, as children become more experienced in the games, they appeared to find them less difficult. Children who used the sign language portion (only 10 children) liked it quite a bit. In fact, in their qualitative comments, most children asked to have the entire story signed, as they are not comfortable with reading English, and would understand much better in ASL. Their comments made it quite clear they are not comfortable with writing English, as their writing was quite often difficult to understand. One of the factors that made the game hard for children was that only the math question portion of the game was signed, and the story was written in simple English. The children struggled to understand the story, and often tried to just skip to the part they could understand.

Post-Game Teachers' Responses

Teachers were asked what they thought children learned. Their responses included compass skills, they could use math in different situations, how to follow and listen to directions, rounding and addition practice, how to use the technological tablets, compass skills (north, east, south, west), teamwork, vocabulary, and problem-solving skills. Teachers thought the children really liked having access to technology and playing the games, as well as getting to work together to figure out problems. One teacher noted the children would ask if they could play the games to practice their math!

Teachers were also asked what they felt the students struggled with in the games. Some of the challenges involved in using the GPS games included the tablets being hard to see, and the children do not like being outside in cold weather. Another challenge was that children quickly learned that they did not have to read the stories, and they would just skip to the questions they needed to answer. When children did read the stories, they struggled with the vocabulary and language used in the games. Another noted that seeing the screen, reading the narrative, and doing the problems were problematic for children. Yet another teacher of younger children noted that children struggled with reading word problems and doing math in their heads (perhaps a doodle pad for working out the problems would help). The children had a difficult time staying focused on the story, while another teacher said most could not read or understand the English.

With regard to student enjoyment of the games, one teacher noted the higher ability children were bored, the lower ability children needed assistance, and the game was just right for about 3 of the 7 children in her classroom. One teacher's assistant noted that they seemed to like it a lot, and in fact, they asked to do it. Another teacher said approximately 50% enjoyed the game and 50% did not. When asked how often children had to ask for assistance the first time that the games were played, teachers said at least once per game. Early in the process, a teacher noted that the children needed quite a lot of assistance. A teacher with 6 children in the project said two of her children had to have 100% assistance, while the others needed 5% assistance the first time they played the game. As children became more proficient at using the games, teachers found they rarely provided any assistance. Similar responses were obtained from another teacher's assistant, who stated, "In the beginning, they needed a lot of assistance, but they seem efficient with it now." Younger children needed help with all of the reading.

When asked about successes experienced as a result of using the GPS games in the classroom, teachers noted that children were faster at the games over time, and having an opportunity to use the technology is extremely valuable for them. The children became faster at mental math and had better orientation and increased technological knowledge. The children were also successful in learning their directions (north, east, south, west) and felt good about themselves when they scored highly.

Children's Math Scores

Children's strongest math skills were in the addition and subtraction areas, with an average of 81% correct answers. Their performance in multiplication and division (38% correct), fractions (4% correct), algebra (23%), decimals (6% correct), and word problems (21%) demonstrated poor performance, which improved over the course of the project, despite the short term of the intervention (December-April). Children scored in the 13th percentile at the posttest, significantly improving their scores ($p < .01$). Their addition and subtraction scores did not improve statistically, although they did increase to 84% correct. Similarly, their performance on the fractions and decimals subtests did not improve either. However, their multiplication skills (50% correct; $p < .01$)), word problem (31% correct; $p < .05$), and concepts and communication in mathematics (41% correct; $p < .001$) all improved statistically over the course of the short term intervention. Unfortunately, there was no comparison group to determine whether the growth experienced by the children was above experienced by similar peers who had not had the opportunity to play the GeePerS*Math games.

EVOLUTION OF MOBILE GAMING

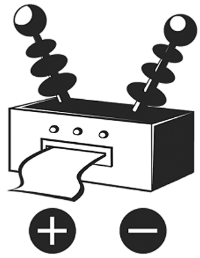
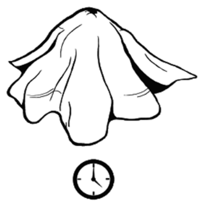
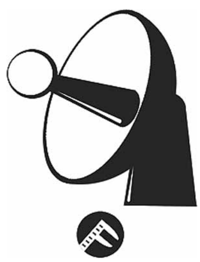
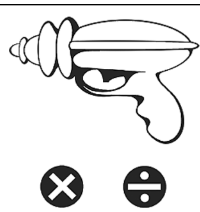
Based on the design feedback from teachers and students, the remaining games of the GeePerS*Math series were completed (see Table 6). A notable difference between the pilot and the remaining games was the change to a female designed to help students navigate through the mapped environment. All five games are available to download and play without charge from the Google Play repository.

CONCLUSION

As previously described, DHH children may have significant vocabulary difficulties, as well as difficulties with math skills and story problems are of particular difficulty. The fact that students self-reported learning orienteering skills, and practiced reading to solve mathematical problems, is encouraging. One of the unintended outcomes researchers observed was peer tutoring and students reading the text of the game out loud as they played. One teacher thought the act of reading out loud was one of the strengths of the gameplay.

Certainly, a quantitative analysis of student learning gains through the use of the GPS modules would greatly assist in examining the extent, and which portions of mathematics, estimation, and rounding skills were most improved. In addition, researchers are interested in how the peer-tutoring

Table 6. Five completed games based on the pilot

Type of Story Problem	Screenshot	Game Title
 Addition and Subtraction		Game 1: *Logic Machine Rescue*
 Time		Game 2: *Adventure on Integer Island*
 Approximation		Game 3: *Treasure of Knowledge*
 Measurement		Game 4: *GeePerS: Episode IV*
 Multiplication and Division		Game 5: *Ickles: The Final Frontier*

and reading skills may have been of benefit over traditional approaches to teaching this material. An intriguing aspect of this population is the number of students who had other cognitive disabilities that were part of the activity: how might the GPS games have assisted them in overcoming their particular deficiencies? This results in this project report point toward the need for further scaling of the technology and research beyond the pilot group.

Teacher participation in the creation of an iterative design for the production of a mobile game to learn mathematics is challenging due to scheduling, curriculum integration, training, and other resource constraints. When targeting a specialized population of DHH children, those constraints can become magnified. Drawing from recommendations of game designers to integrate audience participation in the design and development of games, we approached the project by securing involvement by those who would be using the game the most: the teachers of students who are DHH. Adopting a similar approach to game development used by instructional technologists and learning scientists have proved to be advantageous, in that communications about enjoyable elements infused and aligned with relevant mathematics standards has been possible. With this article, we offer examples of how teachers were utilized to help inform design and development decisions, and by sharing these experiences, we aim to offer insights into the design and development of other educational applications mobile and otherwise.

The resulting instructional systems have the potential to make significant contributions to the education of DHH children in the area of mathematics. There is an increased interest in expanding technology to appropriately address the mathematical needs of DHH students due to the success of other forms of technology that have enhanced DHH individuals' lives (e.g., captioning technology). According to Lang (2009) technology shows great promise to becoming an integral component of mathematics instruction for DHH students.

This project will eventually result in the development of an innovative technology product to optimize DHH children's mathematics learning based on the recommendations of the National Council of Teachers of Mathematics *Standards* documents (NCTM, 1989; 2000), Common Core State Standards, and research on best practices in mathematics education for DHH children. The *Standards* promote the appropriate and increased use of technology to expand instruction and enhance learned material, the use of active learning, application of learning in real-life situations, and integration of learning with other topics (NCTM, 2000). An exciting aspect of this project is its potential contribution to knowledge in the field as described in the previous section, but perhaps especially related to *practice.* By using the strategies and technology to be developed, it is expected more DHH children will successfully achieve mathematics milestones, in turn, improving their chances to reach competency in mathematics.

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