Redesigning Traditional Children's Games to Teach Number Sense and Reinforce Measurement Estimation Skills Using Wearable Technology

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Master of Science in Interactive Media and Game Development

By:

_____

Wendy Leigh Rountree

Date: April 28, 2015

Approved:

_____

Advisor: Dr. Ivon Arroyo

Approved:

_____

Committee: Professor Brian Moriarty

Approved:

_____

Committee: Dr. Charles Rich

Abstract

Children are born with an intrinsic motivation to play games. Over the past decade, educational

video games have invaded mainstream classroom instruction and researchers are "considering

how games might be used in pursuit of engaging, effective learning experiences" (Squire and

Jenkins, 2003). This research encompasses designing math games using a constructivist

and embodied cognition pedagogy in an effort to answer the question: "Will overlapping

wearable technology and mathematical objectives with traditional children's games show

improved efficacy in students' math skills and increase students' motivation to learn math in 4th

thru 6th grade students?" Methods of research include a usability study and four subsequent

iterative studies to improve the game and the technology, measuring students' math self-efficacy

and motivation to learn math. The final goal of this thesis is to design, test and document an

engaging children's math learning game using wearable technology that requires active physical

experiences while involved in deep thinking and complex problem solving (Gee, 2003) within

real world environments, beyond classrooms, pencil and paper, and even beyond traditional

computer games in front of a computer screen.

Acknowledgements

Foremost, I would like to express my sincere gratitude to my advisor Dr. Ivon Arroyo for the continuous support of my Master's project and research. Her immense knowledge and enthusiasm for embodied learning through games has been invaluable in this endeavor.

In addition to my advisor, I would like to thank my thesis committee, Dr. Charles Rich and Professor Brian Moriarty for their insightful comments and encouragement.

A special thank you to Imran Zualkernan, for getting the team started towards wearable technologies for learning and for giving me feedback on the games designed for this study.

I would also like to thank my fellow teammates for their incredible effort on this research: Jennifer Albores, Wil Korb, Wixon, Dylan McCarthy, Alex Silva, Shadi Ramadan, Chris Cerruti, Peter Leondires and Dalton Tapply.

To my family, Mary Jane and Alex, I could not have completed this without your support and encouragement. I will be forever grateful.

Table of Contents

List of Figures

List of Tables

1. Introduction

In an effort to combat falling math scores, schools across the country have started using computer games for math instruction. There has been a major shift in the field of learning from a traditional, didactic model of instruction to a learner-centered model that emphasizes a more active learner role. The movement to use video games as a motivational tool for learning math has been gaining momentum for the past decade so much so that educational games have become widely used in classrooms across the country (Gee, 2003).

However, educational games create a sedentary learning environment in a similar way to traditional classroom instruction, while children's natural inclination is to move, play and explore. Consistent with this idea, there has been a major shift in the field of education from a traditional, didactic model of instruction to a learner-centered model that emphasizes a more active learner role. There is a growing trend in today's games to bring more physical movement and social interaction into both education and game environments while still utilizing the benefits of interactive media, computing and graphical systems (e.g. Lui & Slotta, 2014). Technology-based educational games can enhance how children learn by supporting four fundamental characteristics of learning: (1) active engagement, (2) participation in groups, (3) frequent interaction and feedback, and (4) connections to real-world contexts (Roschelle, Pea, Hoadley, Gordin & Means, 2000).

Educational games can be designed based on the embodied learning theory using wearable technology. The combination of technology, whole body activity and problem solving in children's games has the potential to increase learning gains and provide students with an alternative learning environment to the sedentary learning environment so prevalent in classrooms today. This research uses wearable technology in the form of a CyberHoodie (See

page 30) and a CyberWatch (See page 59) in traditional children's games such as *Math Hide and Seek* and *Math Scavenger Hunt* to teach number sense and reinforce measurement estimation in a real world environment.

This research investigates whether blending wearable technology with traditional children's games will increase students' math efficacy and motivation to learn math in 4th through 6th grade students, at the end of elementary school and at the transition into middle school. The final goal of this thesis was to research empirical game design frameworks, proposes an inclusive educational game design framework based on a combination of several game design framework models and use those frameworks to design an engaging math game with wearable technology. While attempting to understand the effectiveness of these children's games to increase student's math performance, self-efficacy and motivation to learn math.

This thesis discusses educational game design frameworks as a tool for designing educational games and uses a combination of those frameworks to design math games for wearable technology game design (Chapter 4), usability studies (Chapter 5 & 8), technology iterations from paper prototypes to CyberHoodies (Chapter 6), a CyberHoodie *Math Scavenger Hunt* game study (Chapter 7), game design and technology iteration from the CyberHoodie to the CyberWatch (Chapter 9) and the latest game design, *Estimate IT! Adventure of the Kon Tiki* using the CyberWatch (Chapter 10).

2. Motivation

The motivation for this research is multifaceted. Foremost, researchers have found educational games show a positive effect on motivation and learning through the use of games in the classroom (Girard, 2013). This research seeks to determine if the positive effect on motivation and learning through the use of video games in the classroom also transfers to

physical learning games using wearable technology promoting embodied learning (Johnson-Glenberg (2012).

Secondly, many students are identified as multimodal learners in the US. With that in mind, it is important to offer students alternative learning experiences that include physical, visual and aural learning environments to facilitate encoding of new information.

Third, with the embrace of technology in learning environments, this research will investigate the practical feasibility as well as the extent in which a physical learning environment can be created for students integrating math and traditional children's games. Adding wearable technology to educational gaming changes the dynamics of the games by giving "information on demand and just in time, not out of the contexts of actual use or apart from student's purposes and goals" (Gee, 2003).

Fourth, a single educational game design framework has yet to be recognized as the industry standard, therefore, making designing educational games more difficult. For this study, several game design frameworks were compared including the Mechanics, Dynamics and Aesthetics Framework (MDA) (Hunicke, 2004), Adaptive Digital Game-Based Learning Framework (ADGL) (Tan 2007), and SGDA Framework (Mitgutsch, 2012). I propose an inclusive educational game design framework and used this designed framework and Constructivist pedagogy as a guide for creating the *Math Scavenger Hunt* game using wearable technology.

Fifth, computers are used everyday to decrease the cognitive load on the user, saving people from carrying out routine cognitive tasks that a computer can easily perform. The digital nature of the CyberWatch affords student's direct interaction with the technology while physically exploring the game environment creating, building and developing their own cognitive schemas as they play. The CyberWatch frees the student from a large portion of cognitive load allowing

the student to concentrate on higher-level problem solving skills. Will this increase in concentration and cognitive resource use also increase a student's learning and performance, math self-efficacy and motivation to learn math? This research strives to answer that question.

Lastly, wearable technology affords embodied learning and adaptability, which is challenging using traditional teaching methods. Adaptability so far has been applied only to software-based adaptive "intelligent" tutoring systems (Woolf, 2008; Arroyo et al, 2014). This technology encompasses all the benefits of adaptive personalized learning environments while helping teachers gather assessments to better understand their student's skill level and areas of improvement. Teaching the system itself to be a better teaching device by adapting to each student's math skills and identify individual student's progress in real-time giving teachers the opportunity to intervene earlier than traditional teaching methods allow. The adaptive, personalized potential of the technology would change the dynamics of the game itself as the game "operate(s) at the outer and growing edge of a player's competence, remaining challenging, but do-able" (DiSessa, 2000). This adaptability potential is a key factor that should improve learning gains, and make wearable technology a viable tool to use in classroom instruction, desired by teachers and students alike.

3. Background

Teachers are embracing learner-centered education and technology in greater numbers today than 2010 (Games and Learning, 2014). The movement for educational technology in the classroom and Imran A. Zualkernan's (2011) work using wearable, tangible and ubiquitous game-based learning inspired this thesis. Research included investigation in pedagogical theories applied in educational game design and games as learning tools (Gee, 2003). Research revealed instructional approaches based on discovery (Bruner, 1961), experiential (Kolb, 1983), or

problem-based learning (Barrows & Tamblyn, 1980) as well as Constructivism ideas (Jonassen, 1991), which stress the importance of learning environments such as educational computer games. Shifting the learning environment from educational computer games to educational games using wearable technology encompasses a range of pedagogical theories including Constructivism, Embodied Learning, Cooperative Learning and Collaborative Learning. Zualkernan (2011) proposed a new framework for problem posing and problem solving as a pedagogical element in the development of game-based learning systems.

Arroyo, et al. (2011), discussed the design, implementation and pedagogical framework for combining wearable technology with traditional children's games like *Hide and Seek* and *Scavenger Hunt*. Using Malone's Criteria (Malone, 1987) in the design and evaluation of internal and external motivators for players in *Hoodies and Barrels,* the authors determined connecting wearable technology with traditional children's games made the games more interesting and challenging for players, which showed great promise for education.

3.1. Pedagogical Theories

Constructivism.

Constructivism suggests that learners create knowledge as they attempt to understand their experiences (Driscoll, 2000). According to Siemens (2005), classrooms, which emulate the "fuzziness" of this learning, will be more effective in preparing learners for life-long learning. A 2010 pedagogical report from Andriessen, et al. (2010), stated, "Learning objectives presented in constructivism learning environments should be firmly embedded in context, and should, at least in some way, represent every day life situations." Extrapolating on Andriessen's argument that learning objectives in constructivism learning environments be firmly embedded in context and represent a real world situation, learning objectives should be designed so that students can

derive meaning from the connection between the learning objectives and the environment in which the learning goals are presented. One could apply the same criteria to educational game design where a need exists for game mechanics to be directly tied to learning goals and embedded in context in order to increase students self efficacy, motivation to learn math and individual learning gains.

Constructivism, as a pedagogical theory, is conducive to both virtual and real exploration games and open world games where students can test their premade schemas in a real world environment. Constructivism learning environments are model situations for embodied learning to occur.

Embodied Learning.

According to Dr. Mina Johnson-Glenberg (2012), Chief Learning Officer, of SMALLab Learning LLC., embodied learning theory has a very specific meaning for learning scientists, that is – comprehension and retention are affected by sensory motoric input.

Margret Wilson (2002) describes cognition as situated, time pressured, limited, and environment dependent, action and body based. Wilson argued that emphasizing the case, for situated cognition might interfere with our understanding of the parts of cognition that are in fact situated. Wilson pointed out spatial cognition as an example when situated cognition is necessary. Wilson adds, "Trying to fit a piece into a jigsaw puzzle, for example, may owe more to continuous reevaluating of spatial relationships that are being continuously manipulated than it does to any kind of disembodied pattern matching (Kirsh & Maglio, 1994)."

Wilson refuted the idea that cognition is time pressured siting many daily activities where time pressure is nonexistent. Wilson pointed to "video games" as the exception as "time pressure is inherently part of the task" of playing.

In defining the difference between online cognition and offline cognition, Wilson identifies online cognition as normal everyday problem solving abilities and offline cognition as a gradual, more in depth thought process. Wilson argued, "off-line cognition is body based" as the best documented and most powerful of the six claims.

Embodied learning fixates on individual cognition where learning methodologies like collaborative learning and cooperative learning involve sharing knowledge in groups or teams are quite different in task distribution.

Collaborative Learning.

The term "collaborative learning" refers to an instruction method in which students at various performance levels work together in small groups toward a common goal. The students are responsible for one another's learning as well as their own. According to Bruffee (1995), "collaborative and cooperative learning were developed originally for educating people of different ages, experience, and levels of mastery of the craft of interdependence." Bruffee (1995) stated, "Collaborative learning began with an observation that is arguably the flip-side of cooperative learning's intention to reduce competition among individual students- the observation that the hierarchical authority structure of traditional classrooms can be educationally deleterious, because it establishes what Mary Louise Pratt calls 'contact zones' that isolate students from each other. One effect of this isolation is to fuel student competitiveness."

As Gokhale (1995) found, proponents of collaborative learning claim that the active exchange of ideas within small groups not only increases interest among the participants but also promotes critical thinking. According to Johnson and Johnson (1986), there is persuasive evidence that cooperative teams achieve at higher levels of thought and retain information longer than students who work quietly as individuals. The shared learning gives students an opportunity

to engage in discussion, take responsibility for their own learning, and thus become critical

thinkers (Totten, Sills, Digby, & Russ, 1991). In Vygotsky's (1978) view, students are capable of

performing at higher intellectual levels when asked to work in collaborative situations than when

asked to work individually. Group diversity in terms of knowledge and experience contributes

positively to the learning process. Bruner (1985) contends that cooperative learning methods

improve problem-solving strategies because the students are confronted with different

interpretations of the given situation. The peer support system makes it possible for the learner to

internalize both external knowledge and critical thinking skills and to convert them into tools for

intellectual functioning.

Gokhale argued, "Collaborative learning is heavily rooted in Vygotsky's views that there

exists an inherent social nature of learning which is shown through his theory of "zone of

proximal development" often abbreviated as ZPD, is the difference between what a learner can

do without help and what he or she can do with help.

Bruffee (1995) found, "cooperative-learning pedagogy tends to undercut collaborative

learning's aim to shift the focus of authority from the teacher to student groups."

Cooperative Learning.

Cooperative learning, a term coined by Slavin (1980), refers to instructional methods in

which students work in small groups to help each other learn. Although cooperative learning

methods are used for different age groups, they are particularly popular in elementary (primary)

schools. Bruffee (1995) found "cooperative learning began with the observation that competition

among students sometimes impedes learning." An important goal of cooperative learning is to

hold students accountable for learning collectively rather than in competition with one another.

Slavin (1995, 2010, 2013) identified motivationalist, social cohesion, cognitive developmental, and cognitive-elaboration as the four major theoretical perspectives on the achievement effects of cooperative learning. In contrast to collaborative learning where groups of students work to achieve the same goal, individual students are given a specific task to solve or work, which complements the roles/tasks of other students in the same team and encourages acountability. A typical form of cooperative learning is the "jigsaw" method, in which students have different tasks (or hats) where each of them is assigned a very specific task. Everybody has to succeed in his or her individual tasks for group success.
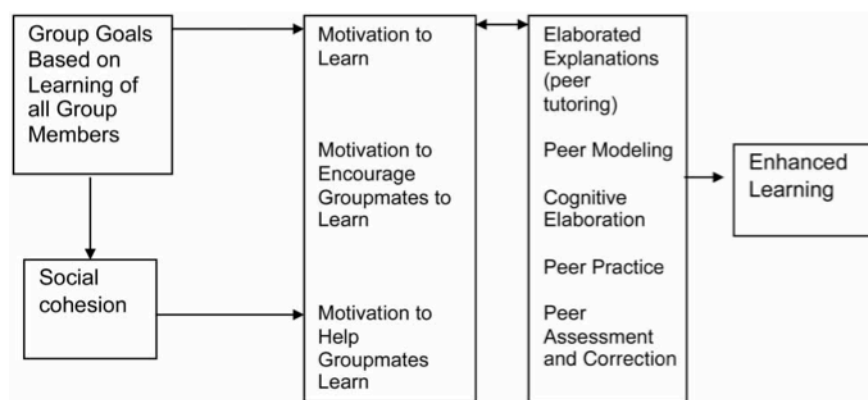
Figure 1 Slavin's Theoretical model.

According to Rockwood (1995a, 1995b), collaborative learning and cooperative learning and cooperative learning are quite different. Rockwood identifies the differences between these methodologies as one of knowledge and power: Cooperative learning is the methodology of choice for traditional knowledge while collaborative learning is connected to social constructivism's view that knowledge is a social construct. He further distinguishes these approaches by the instructor's role: In cooperative learning the instructor is the center of authority in the class, with group tasks usually more closed-ended and often having specific answers. In contrast, with collaborative learning the instructor abdicates his or her authority and

empowers the small groups who are often given more open-ended, complex tasks. As this research shows, both methodologies would be well suited in educational games.

3.2. Educational Game Design

Educational Games As Learning Tools

In the past decade, digital games have emerged as viable learning tools (Takeuchi, 2014). Educational games adopted in the early 90's were "skill and drill" exercises in video game format. A few of the most popular educational games included titles like *Math Blaster* (Rice, 2007) and *Reader Rabbit* (Wilson, 2009). Educational games have evolved to include better graphics, various 2D and 3D platforms and more dynamic gameplay.

As video games have become more appreciated as viable learning implements, more teachers are utilizing them to supplement the curriculum in classrooms across the US. A 2014 Games and Learning research report, Millstone (2012) identified that 78 % of teachers use video games in the classroom, up from 50% two years ago and 55% of teachers reported having their students play video games at least weekly. Even as teachers are becoming more receptive to using video games as teaching tools, 80% of teachers wish it were easier to find digital games that align with curriculum standards. This request from teachers has encouraged more academics to weigh in on which pedagogical theories are best suited for educational game development.

Pedagogical Influences in Educational Game Design

Academic influence in creating an educational game design framework relies heavily on pedagogical theories, learning objectives, assessment and learning gains. Pedagogical theories used in educational games include: Behaviorism, Cognitivism, Humanism and Constructivism.

Behaviorism in games includes learning through a change in behavior and the principle of reinforcement. Cognitivism includes how the memory and prior knowledge plays an important

role in learning. Humanism theory deals with factors such as self-determination, the value and potential of the user. Constructivism theory deals with human constructing their knowledge through experience and learning in active process (Ahmad, 2014).

Understanding of the cognitive and metacognitive processes and how they can be included in the design framework will add intrinsic motivation for and a deeper understanding of learning goals and their relationship to game mechanics.

Game Designers, Game Mechanics and Game Play

Gee (2005) identified 16 learning principles games offer players: identity, interaction, production, risk taking, customization, agency, well-ordered problems, challenge and consolidation, just in time and on demand feedback, situated meaning, pleasantly frustrating, system thinking, exploration, distributed knowledge, cross-functional teams and performance before competence. Game designers can use mechanics to fit learning objectives once they understand pedagogical theories and how those theories can shape the game environment and gameplay. Focusing on mechanics will allow for engagement over information where the information learned will be intertwined and directly related to mechanics throughout gameplay. By using a leveling mechanic where a player only advances in the game based on their mastery of the content, game designers can incorporate assessments into the game design. Specifically, how games like *Hide and Seek* (Arroyo et al., 2011) and *Scavenger Hunt* (Klopfer et al., 2005) can be modified to reinforce measurement estimations and number sense. Modifying game mechanics in both games affords intrinsic and extrinsic motivation and opportunities for learning to occur.

Expert Teachers, Practical Implementation and Playtesting

Expert teachers are in a unique position to implement educational games in classroom curriculum. Because of this, expert teachers can playtest educational games designed from various educational game design models and provide feedback on which models or parts of models were successful. Feedback from expert teachers on educational game design frameworks has yet to be addressed when discussing a standardized educational game design framework. Information on how educational games perform in classrooms is limited to learning gains. By involving expert teachers in the framework design process, a unique lens will shine on educational games and improve educational games as a viable learning tool. Involving expert teachers in analyzing educational game design frameworks will result in a more robust framework, which will make incorporating educational games in classroom curriculum less difficult and increase learning outcomes.

4. Towards a Comprehensive Educational Design Framework

Research has shown a need for a comprehensive educational design framework, which encompasses many elements of established design frameworks. A comprehensive educational design frame work focuses on three areas: game design elements included in the MDA framework, pedagogical aspects described in the ADGBL framework and purpose and framing included in the SGDA framework, as described in more detail below.

4.1. Mechanics, Dynamics and Aesthetics Framework (MDA)

The MDA framework (Hunicke, LeBlanc and Zubeck, 2004) is currently being used as a tool to analyze games. With the addition of pedagogical models and key participants such as expert teacher and academics, the MDA framework can be adopted for use in educational game development as a part of a viable game design framework. Hunicke (2004) explains, "Mechanics

describes the particular components of the game, at the level of data representation and algorithms. Dynamics describes the run-time behavior of the mechanics acting on player inputs and each other's outputs over time. Aesthetics describes the desirable emotional responses evoked in the player, when she interacts with the game system."

The MDA framework breaks down games into their individual components and their design counterparts:
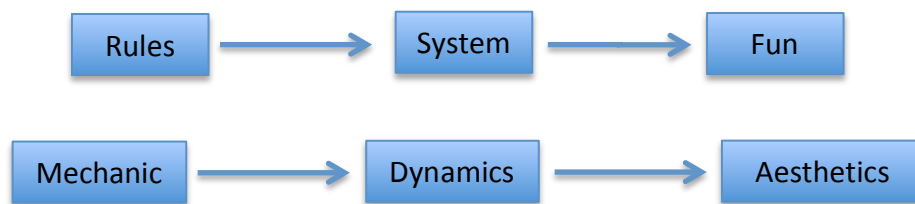
Figure 2 MDA framework

Researchers and game designers have noted this promising technology and proposed several frameworks and models to foster multimedia-learning environment. However, most of these models do not address the learning behavior in game design, which is important to facilitate learning process in game based learning.

4.2. Adaptive Digital Game-Based Learning Framework (ADGL)

The Adaptive Digital Game Based Learning Framework addresses pedagogical influences in educational game design. Tan (2007) designed an educational framework divided into two parts, pedagogical and game design (see Figure 3). The pedagogical model addresses psychological needs, cognitive development and learning behaviors. The only addition to the pedagogical model which research suggest should be added is metacognition (Kim 2009). Note how the game design element in Figure 3 could correspond to the MDA game design framework (Figure 2). Designing educational games implies a delicate balance of the two sides of this framework: the educational/learning objectives on the left, and the engagement/entertainment component on the right side.
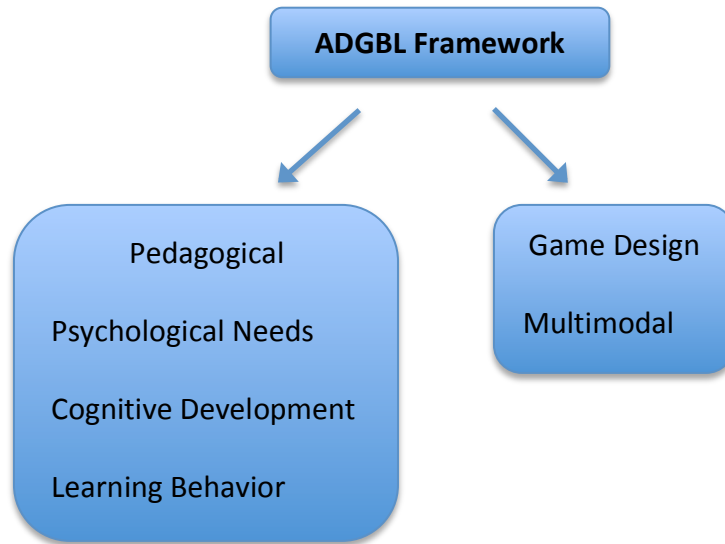
Figure 3 ADGBL Framework

4.3. SGDA Framework

Mitgutsch (2012) describes the SGDA Framework in six elements: purpose, content, fiction and narrative, mechanics, aesthetics and graphics and framing. The purpose of the game is explicitly designed for a purpose greater than gameplay alone. Thus, the purpose should be reflected in all the elements that support the game system: content, information, facts and data offered and used in the game; the fiction & narrative, Charsky (2010) argues, this fictional context involves "the setting, narrative, story, scenario, characters, back story, problem, and so on for the game play;" the mechanics, game mechanics are the "methods invoked by agents for interacting with the game world;" the aesthetics & graphics, audiovisual components and the framing; target group, play literacy and broader topic of the game. The relation among these six core components impacts the coherence and cohesiveness of the formal conceptual design of the holistic game system.
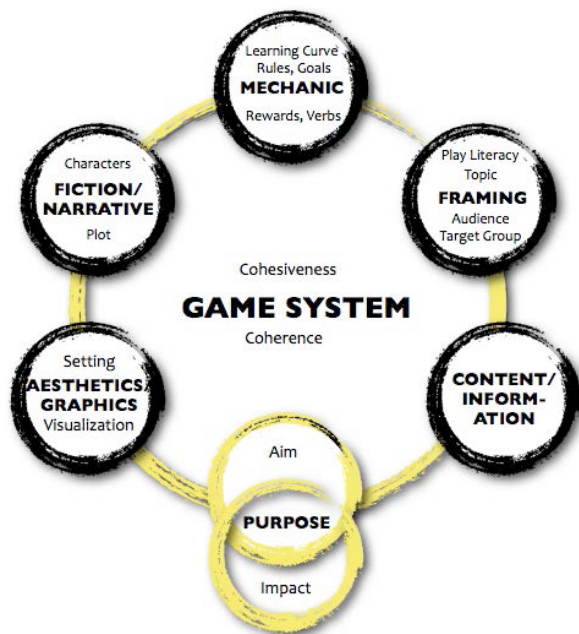
Figure 4 SGDA Framework

Note that there are several elements that overlap between the SGDA framework and the

MDA framework: the mechanics and aesthetics components are repeated in both models. The

fiction/narrative and content/information component could be part of the aesthetics and the

dynamics of the MDA framework. Elements that are not present in the MDA framework are the

"framing" component, which imply carefully targeting your audience, and purpose, clearly

understanding and defining the objective of the game.

The SGDA framework is much richer than the MDA framework for all these reasons.

4.4. Comprehensive Educational Game Design Framework

As stand alone models, each game design framework has merit. By combining aspects of

these models, each discipline is represented resulting in a more comprehensive educational game

design framework. I specify a new educational game design framework in Figure 5, called the

Comprehensive Educational Design Framework (CEDF), which takes the student player, needs

and other psychological characteristics, as an essential part of educational game design together

with existing theories, identifying new needs of interaction between actors in the game design process.
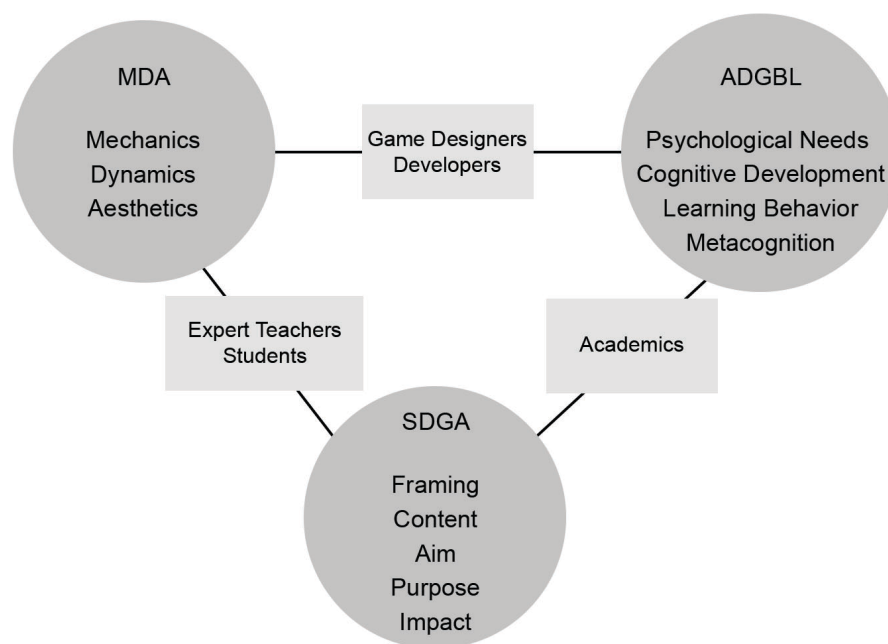
Figure 5 Comprehensive Educational Game Design Framework.

MDA regards the nature of the game itself, ADGBL regards educational and psychological factors of students, and SDGA regards targeting/aiming the game correctly given the human population that it is targeted for. Different professionals are required at each intersection.

Many papers have been written on the importance of educational game design frameworks and game design elements. Schell (2008) includes mechanics, story, aesthetics and technology as game elements. The story or narrative appears as an important design element in almost every design framework. As technology has progressed, an emphasis on aesthetics and technology platform has come to the forefront in educational game design framework analysis and design. Aleven (2010) calls for a combined approach to educational game analysis.

Establishing an educational game design framework including learning objectives, MDA, and Instructional Design Principles would help meet the need teachers are facing in the classroom with few games where game learning objectives match curriculum learning objectives. Echeverría (2011) also includes immediate feedback, exploration and discovery as game design elements necessary to an educational game design framework. With a standardized comprehensive educational game design framework, educational game development will be less cumbersome and the industry as a whole will be elevated as a result of maintaining that standard. I used the CEDF in the design and development of the following measurement estimation games and current game iteration.

To test the validity of our hypothesis, combining math and traditional children's games, a team of undergraduates, Principal Investigator Dr. Ivon Arroyo and myself conducted a usability study to determine students' motivation to practice and learn math playing traditional children's games.

5. Usability Study

The usability study included three students in grades 1 through 5 who played the *Math Scavenger Hunt* game without technology in a public park in Worcester, MA. The game was designed as a motivational tool for students to practice math and develop estimation skills outside the classroom in a real world environment.

Gameplay Description

The objective of the game was to find shapes on a playground. All participants were given a stack of color coded index cards with 25 clues, and were expected to find the corresponding sticker, in color and number, located on the playground.

Figure 6 Index Card Deck

The clues were of various measurements, which correspond with marked objects on the

playground. Sample clues included, "Find a rectangle 2' wide by 14" long." and "Find a grid

with rectangles approx. 3.25 in by 2.25 in."
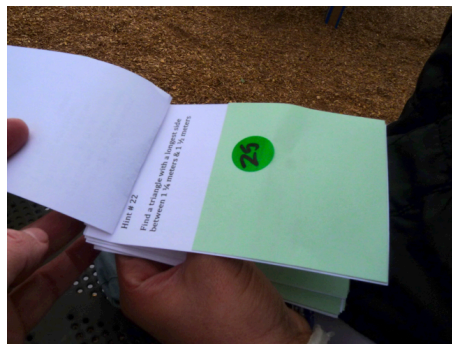
Figure 7 Color Coded Index Card and Matching Sticker

The participants were given 20 minutes to find as many stickers/objects as possible, using

the clues they were given, and were asked to place the stickers on the corresponding index card.

The total number of correct answers determined the winner. The participants played one round of

the game, were asked to fill out a survey after the game and participated in a debriefing where

they described their thoughts on the game.

Data Collection

Data was collected through experimenters' observations and by administering a 5-point

Likert scale questionnaire (See Table 1) to the participants. The questionnaires consisted of 7

questions (See Appendix A) "How much did you enjoy this game?"; "Did you use your math by playing this game?"; "Do you think you learned math by playing this game?"; "Would you play it again?"; "How Challenging was this game?"; "How much do you like learning math sitting in the classroom?"; and "Would you like to learn math moving and running like this?". Participants were asked to circle their answers with a 1 being "Not at all", 2 being "Just a bit", 3 being "Sort of", 4 being "pretty much" and 5 being "very much"; the only difference being the answers to the question, "Would you play it again?" The answers were: "Not at all", 2 being "One more time", 3 being "A few more times", 4 being "Several times more" and 5 being "I'd play it everyday".

Usability Study Survey Results 10/27/13

Question	Average
How much did you enjoy this game?	3.6
Did you use your math by playing this game?	3.3
Do you think you learned math by playing this game?	3
Would you play it again?	3.6
How Challenging was this game?	3
How much do you like learning math sitting in the classroom?	2.3
Would you like to learn math moving and running like this?	4.3

Table 1 Usability Survey Results

Student Survey Results

The usability survey results show the students enjoyed the game, felt they learned and used math and would prefer learning math moving and running like they experienced playing the game. The students found the game to be more challenging than the game designer expected and this was taken into consideration in the next game design iteration. We did not run any statistics on this data given the small number of students.

Student Debriefing

Students responded to the game in the debriefing by making several important statements such as: "I can't do the math in my head"; "It's hard to keep track of which one I am looking for"; "The questions were hard"; "The game was fun"; and, "I would play again".

Observations

Running and computing at the same time was difficult for players without free hands, occupied managing cards, stickers and tools. Instead of following our hypothesis of players using clues to find correct locations, players tended to cheat at least to some extent by matching numbers with stickers instead of doing math to find correct locations. The players had difficulty flipping through the cards, remembering what clue they were looking for and mismatched stickers during the confusion. In response to the confusion, players relied heavily on observers/researchers for extra help. While once players arrived at the location they wanted to measure, some players had trouble reading the measuring tape and deciphering measurements, indicating poor familiarity with the tools themselves or measurement ability. Players often asked observers for help in using the tools and this slowed down the flow or pace of the game as a result. Outdoor gameplay boundaries were difficult to determine and players were often asked to return to the gameplay area.

What We Learned

Based on the results of the usability study showing students would rather learn math running and playing games than sitting in the classroom, we moved forward in designing a measurement estimation game that students would be able to play using wearable technology affording free movement in the learning environment. Responding to the player's statement, "I can't do the math in my head," we realized technology could play a significant role in gameplay

by affording players the opportunity to share cognitive load with the device. Using the CEDF, expert teachers were asked to review the curriculum standards, clues and scaffolding hints to synthesize curriculum standards and game objectives based on students' skill level. Through technology we could scaffold students by providing hints on the fly, meeting each player at his or her current skill level. Also, meeting each player at his or her skill level would allow to keep the game engaging and increase challenge along with player efficacy.

We also realized how important the game tools were for players and how they could help or encumber gameplay. In the usability study, players had many tools available for use in problem solving, including: a tape measure, a carpenters square, calculator, pencil and paper. This observation changed the game design to only include 3 tools students could use with the technology, changed the level of difficulty from randomized to structured from the lowest difficulty level to the highest difficulty level. We designed a variation of the traditional children's *Scavenger Hunt* game and included measurement estimation objectives, game mechanics, in addition to after-game surveys and player debriefing. In place of stickers, we used colored Easter eggs, and instead of a local park, we used a school gymnasium. Many of the objects in the gym were used as hiding locations. The game location and objects within the game location became a cause for concern when after surveying the area; objects used in the game were missing due to gym classes needing them for training. Game clues then needed to be altered or discarded on the spot.

6. From Paper Prototype to CyberHoodie

The paper prototype described in Chapter 6 demonstrated areas where technology could increase the flow of the game and provide individualized learning through scaffolding. The technology seen in Figure 8 is a vision of the infrastructure needed to play traditional children's

games in the playground (in a local area network of 100 feet around the router and the server) using wearable technology.
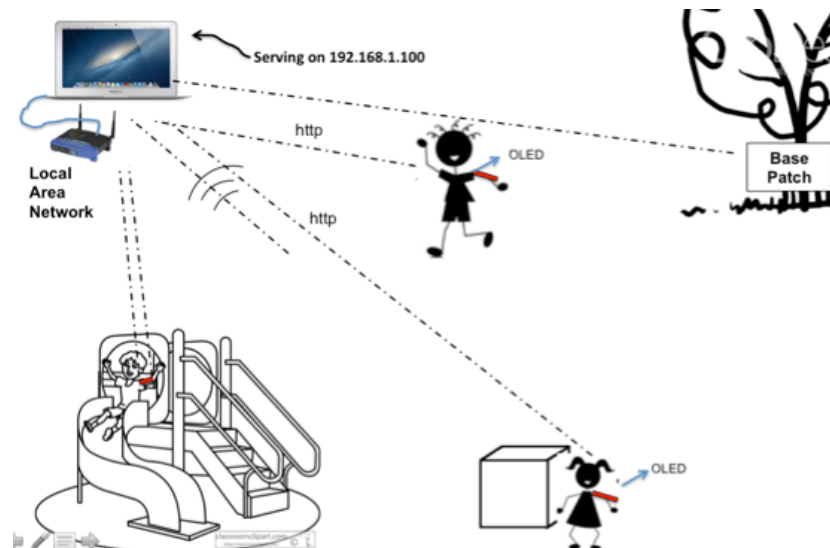
Figure 8 Vision of the Technology Infrastructure for Children's Educational Games

With the technology, players would have the clue text displayed on a LED display instead of having to carry a stack of cards in their hands. The removal of the cards afforded players more freedom to move using free hands. Without technology, players increased or decreased the difficulty of clues by rearranging the cards to find clues that could easily be solved. Instead of players being able to flip through cards, the technology should facilitate this player difficulty self-regulation and automatically adapts the clue difficulty to the individual player's skill level.

As part of this vision, players would be fitted with CyberHoodies (zip up sweatshirt with a hood and integrated technology). Instead of using a shirt, we chose to use various size zip up hoodies that could accommodate a broader range of students. The hardware included: the Arduino, sewn onto a patch on the back of the Cyber Hoodie along with the battery, relay, wiring, LED, clue button and hint button. Players are then given an overview of the game rules and a device tutorial.
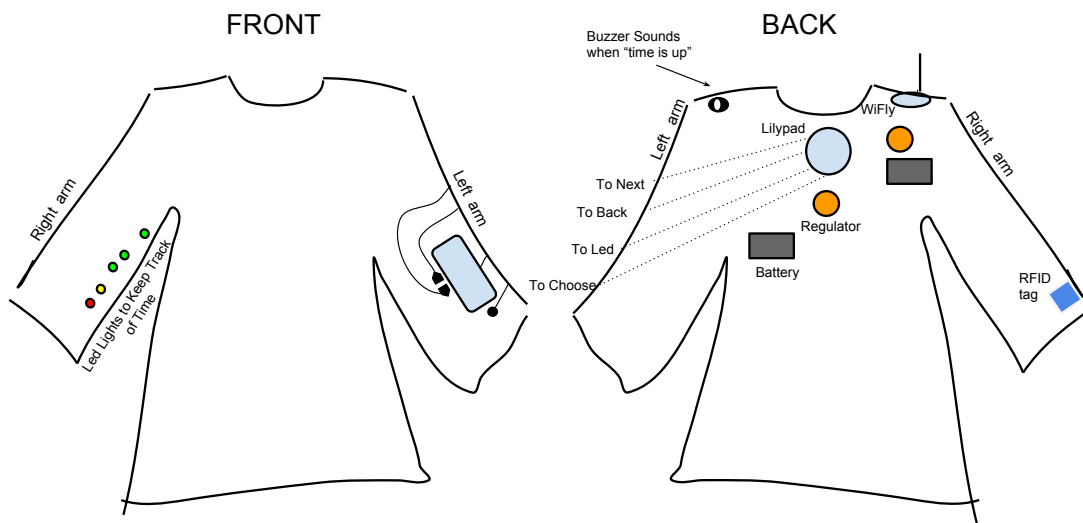
Figure 9 Vision of the CyberHoodie Design (not fully implemented)
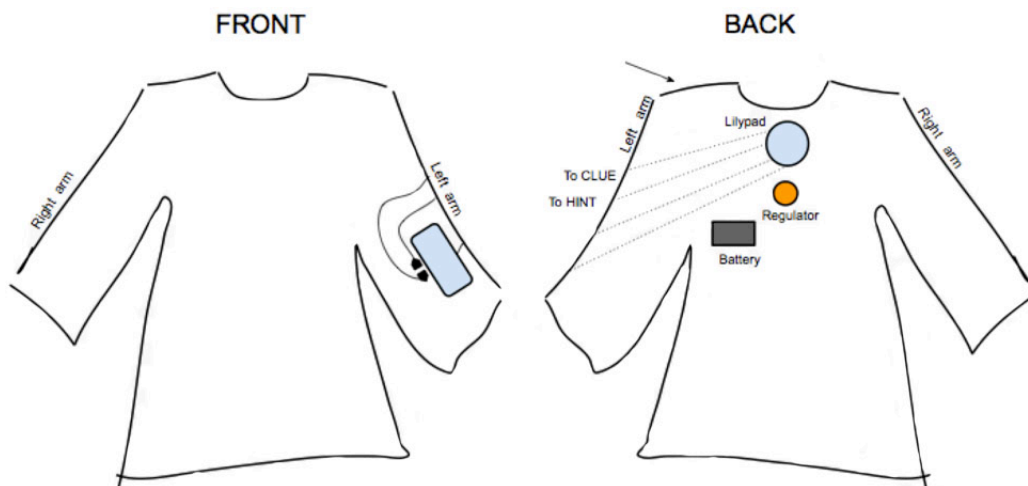
Figure 10 CyberHoodie First Prototype Design

The CyberHoodie was implemented as a first stand-alone prototype (See Figure 10), which included the Lilypad, regulator, battery and LCD, but not the WiFly connection.

The CyberHoodie hardware (See Figure 11) included: the battery, regulator, Lilypad and WiFly. WiFly provides embedded designers with a simple data pipe through which to send data over a Wi-Fi network creating a simple 'wireless serial cable' (Microchip, 2015). All components were assembled on a patch that was attached to the back of the CyberHoodie.
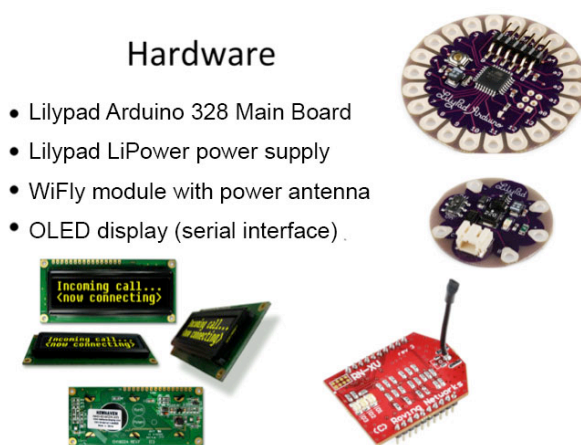
Figure 11 CyberHoodie Hardware List

Figure 12 shows a CyberHoodie prototype created by a learning sciences team, which included Principal Investigator (PI) Arroyo, this researcher (Leigh Rountree) and graduate and undergraduate students at WPI. The back of the hoodie includes the Arduino-Lilypad ATMEL 328-based microcontroller, connected to a WiFly module and powered by Lithium batteries (pockets). Conductive tape was used to make wired connections for this prototype. The OLED on the sleeve communicates to the Lilypad via a Serial RS-232 protocol. The rough edges of the display were covered with Neoprene fabric.

This first technology design iteration hoped to solve several negative issues found in the usability study. In the usability study, both clues on the cards and objects were numbered (via stickers with numbers) to denote which corresponded to each other. Students would cheat by

matching up the numbers, thus defeating the purpose of making the search of the object the target of the scavenger hunt. We realized early on that replacing stickers with undistinguishable RFID tags would solve this problem. In the usability study, participants had to keep track of several notecards with clues, as well as further stickers with hints to help with those clues. Having students' clues and hints distributed digitally on LED display badges reduces the amount of paper the participants (and researchers) need to keep track of.

During the usability study, participants occasionally took too many stickers (some of which did not belong to them), which caused other players to question their estimation skills as they searched for the missing stickers. Since data can exist in multiple places at once (unlike stickers) participants could swipe on RFID tags multiple times without impacting other participants' play. Multiple possible solutions to one same question could also be recorded so that several objects/places could become potentially correct answers.

Figure 12 Actual CyberHoodie Prototype and LED

In summary, through the affordances of technology, we can reduce the cognitive load on the player and allow the player freedom of movement using free hands. The technology affords a personalized kind of game that adjusts level of challenge (similarly to intelligent tutoring

systems), while making advanced data mining a possibility where little to none existed. With wearable technology, we may be able to record students' moves (objects sought correctly or incorrectly), step by step.

7. Math Scavenger Hunt Game Design

Using the CyberHoodie technology and the CEDF, the author designed a variation of the traditional Scavenger Hunt game by including measurement estimation learning objectives and scaffolding, step-by-step information which fade as players gain control over the game objectives (Kebritchi, 2008).

Math Scavenger Hunt was designed to help students increase their math self efficacy and motivation for learning math using an inclusive educational game design framework that included pedagogical theory and game mechanics which fit the learning objectives in an exploratory environment. The game was designed to adhere to 4th thru 6th grade math standards in geometry and measurement estimation, focusing on geometry facts, number sense and measurement estimation. The design pillars or the foundations of the game are the learning objectives, learning pedagogy, game mechanics and technology. Expert teachers helped to develop clues and scaffolding hints, which matched math curriculum standards for $4^{th} – 6^{th}$ grade students.

Theoretical Analysis of the Game. The game design was analyzed using Zualkernan's Pleasure Framework (See Figure 13) and the CEDF to identify areas where the game design could both positively and negatively impact the player's experience. Thru the analysis, the author identified 11 of the 15 pleasures as being a positive impact on the player's experience with exploration and discovery at the top of the list. This analysis allowed the author to see the

potential for players to create their own clues adding a learning opportunity for players using problem posing.

Pleasure Framework

Pleasure	Current Situation	Possible Additions
Creation	Not Present	Player created clues.
Exploration	The game area is scattered with various objects to explore.	Players create/setup gameplay area.
Discovery	Players discover clues based on their problem solving/ estimation skills.	
Difficulty	Clues are from 4th-6th grade common core standards and time limits for each clue increases the challenge.	Clues vary in difficulty based on player skill.
Competition	Teams compete to score the most points.	Larger teams or have a relay race component to give each student a chance to play.
Danger	Players are given a choice to risk for extra points.	Point deduction for finding wrong clue.
Captivation	Players focused when doing manual calculations.	
Sensation	Physical running/walking to find hidden clues.	Lights and buzzers added to hoodie.
Sympathy	Not present	
Simulation	Simulation is not present as one of the goals of the game is to teach how math can be found and used in real world environments.	

Pleasure	Current Situation	Possible Additions
Camaraderie	Teams collaborate to solve problems.	Add more players. Relay race mechanic would increase encouragement.
Subversion	Not Present	Add a cheat for struggling teams.
Recognition	Game is played in front of an audience/class. Winners are announced and prizes are given at the end of each game.	LED shows who is winning.
Control	Players have no control over which clues are given however, they do have control to risk for extra points.	Players map out and create clues for game area.
Performance Feedback	Feedback is given when players check the egg.	Feedback is immediate through RFID Tag/LED.

Figure 13 Pleasure Framework Analysis of the Math Scavenger Hunt Game

Collaboration and competition help players master the game in a 3D real world environment by knowledge sharing and an intrinsic motivation to win. The learning experience from the measurement estimation game is an authentic learning experience in the same vain as carpentry and cooking where learning is attached to the experience.

One difficulty in educational game design is attaching meaning for the students to the learning objectives. In part, player agency/ control increases player confidence and that confidence drives meaning for some players. Based on the results of the usability study, by designing exploration and discovery into the game, players were motivated to practice math in an

informal learning setting like the *Math Scavenger Hunt* game. Through exploration, players were able to move around the game area weaving between game objects of various shapes and sizes i.e., wooden trapezoid stand and metal cabinet/rectangular prism. Discovery is inherently embedded in the game as the players are looking for a specific object at a specific location. In the absence of player creation, an addition to the game design is to allow players more creative control of the game environment and learning objectives. Players might enjoy creating the play area as well as embarking themselves in problem posing (creating the questions/sought object clues themselves). Players would be able to map the area, survey the various objects, categorize the objects and create game clues and hints for a game scenario their classmates can play.

Being able to vary the game challenge for individual players can possibly increase player efficacy. Adding teams as competitors has the potential to increase player's efficacy through cooperation and collaboration. The reader will see later how players wanted more competition and more teams. They also suggested a time constraint to add pressure on the competing teams and keep the game from lagging. Players were captivated while playing the game losing a sense of time and exhibited an extended level of focus. In the current game design iteration, *Estimate IT! Adventure of the Kon Tiki* in Chapter 9, we wanted to find a way to extend the players focus in certain game situations. To build on players concentrated focus, the game was designed to establish continuity in shapes from squares to rectangles and rectangles to other polygons. By designing the game in this manner, players saw no discontinuity in the objects they were searching for and the learning objectives they were trying to meet. With the current technology iteration, performance feedback will be simultaneous and immediate across teams down to the individual player.

The *Math Scavenger Hunt* game was used in the subsequent four studies conducted at Southbridge Middle School in Southbridge, MA from May thru June of 2014 on four separate days using the CyberHoodies.

8.   Usability Study 2

8.1. Southbridge Study Math Scavenger Hunt Game Day 1 - 4/9/14

Math Scavenger Hunt is a measurement estimation game designed for $4^{th} – 6^{th}$ grade students focusing on geometry facts and math skills. 16 students in $5^{th} – 7^{th}$ grade participated in the study on four separate days. In a small gym, different color plastic eggs were hidden behind various objects/geometric shapes already located in the gym for players to find. Players competed in teams of two to solve the math clues displayed on their CyberHoodie LCD screen positioned on the left arm of the hoodie. Clues started off fairly easy and increased in difficulty through the duration of gameplay.

Based on student's responses and researchers observations of the gameplay, a few game design iterations were made to the *Math Scavenger Hunt* game before the next study. First, instead of having students use many different tools, we chose to limit the tools to measuring tapes and a clipboard with paper and pencils to use for math calculations. Second, we added a point base so that students had a choice to check the object themselves, which gave them two points, before turning in the object to the researchers to check the answer for them, which only rewarded one point. We imposed no penalty for students who asked researchers to check the answer for them. Third, we only allowed the students to search for one object at a time. We also added a penalty for incorrect answers, which deducted time from the student's game where they had to stand in place for ten seconds if the students chose to check their own answers and were wrong. Lastly, we added prizes for all the students at the end of the game. All students were able

to choose from several prizes, which included candy, movie cards and game cards. The rewards for playing the game did not change throughout the Southbridge studies.

Gameplay Description

Two teams of two 6th grade students, two girls and two boys were fitted with CyberHoodies (zip up sweatshirt with a hood and integrated technology) that include the Arduino, battery, relay, wiring, rolling LED display, question button and hint button. Players were given an overview of the game rules and device tutorial before the start of the game. The game took place in the school gym and used gym equipment as hiding places for the eggs.

When the game started, students checked their LCD screen for the question, discussed the question with their partner and started searching the play area (See Figure 14) for the object that corresponded with the clue on their LCD.

Figure 14 Math Scavenger Hunt Game Area

If the players needed hints for the questions (math clues for objects sought), they pushed the hint button on the hoodies and the text hint appeared. Both teams had different sets of 6 questions (associated to 5th grade common core standards) per team with 1 hint for each

question and a different set of 6 eggs to find. The team with the most points at the end of the game won.

The Game Rules:

Players can use measuring tapes supplied by researchers to check their estimation skills.

Players can ask game researchers for clue clarification.

Players can choose to look inside egg for extra points- if right then they got 2x points - if wrong freeze in place for 10 seconds - continue to look for right egg

Players can choose to have scorekeeper check egg - if right get 1x point - if wrong face no penalty continue to look for right egg

Players can only turn in one egg at a time.

Players cannot use calculators.

Players cannot leave play area until the end of the game.

Players were given an overview of the game rules and device tutorial before the start of the game. The game took place in the school gym and used gym equipment as hiding places for the eggs.

Data Collection

Data was collected through experimenters' observations and by administering a 5-point Likert scale questionnaire to the participants. The questionnaires consisted of the same 7 questions used in the first usability study.

Game Survey Results Day 1. First Iteration 4/9/14

Question	Average
How much did you enjoy this game?	4.75
Did you use your math by playing this game?	4.75
Do you think you learned math by playing this game?	3.5
Would you play it again?	5
How Challenging was this game?	3.5
How much do you like learning math sitting in the classroom?	2.5
Would you like to learn math moving and running like this?	4.75

Table 2 Game Survey Results Day 1 First Iteration

Student Survey Results and Student Debriefing

The survey results showed more students felt they used math than learned math. One

student stated, "I learned a little math playing the game." The students indicated they enjoyed the

game and would play again. Students said the game was challenging which added to player

engagement. Students indicated they preferred to learn math while moving and running as

demonstrated in the game to learning math sitting in the classroom. Students liked wearing the

hoodies and thought "the hoodie was cool" and "liked wearing technical gadgets." Students felt

having more teams and a time constraint would make the game more fun.

Observations

Math Scavenger Hunt was designed as a collaborative problem solving game and

researchers were surprised to see very little collaboration among students. One student was

reading the questions and the hints while the other student just peeked on the other one's arm.

Only one student in the team of two was writing and doing the math, while the other was kind of

going along with the first. The lack of communication between team members surprised the researchers.

There seemed to be no time pressure at the beginning of the game as students casually walked around the play area and discussed the questions. Both teams were very dependent on the measuring tapes and used very extensive multiplication. No use of estimations occurred.

What We Learned

Students were too scared of penalties to risk looking at eggs themselves, choosing to allow the researchers to check their answers instead. We learned we can use technology to address penalties and rewards adding red, green and blue LED's to signal to the player right or wrong input by displaying either green or red and a small buzzer communicating to the player through various vibration patterns.

The students enjoyed playing the game and thought the hoodies and display were cool. They criticized some of the aesthetics and said the hoodies "could look better." The hoodie needed buttons on the armband to be able to play back the question and hint for easier navigation. Both teams navigated the technology with little difficulty apart from missing a back button.

8.2. Southbridge Study Math Scavenger Hunt Game Day 2 - 5/16/14

Game Design Iteration Based on Day 1 Study

Based on feedback from students and researchers, several game design iterations were made. Two questions were changed due to missing objects in the gym. We replaced the measuring tapes with a blank 12" dowel, hoping that this would encourage some measurement estimation, instead of exact measurement and full-fledged computation. All other components of the game stayed the same as the previous study.

Game Description

Game description was unchanged. In the study, four students in teams of two competed to win the game.

Game Survey Results Day 2. Second Iteration 5/16/14

Question	Average
How much did you enjoy this game?	4.75
Did you use your math by playing this game?	4.75
Do you think you learned math by playing this game?	3.5
Would you play it again?	4.75
How Challenging was this game?	4
How much do you like learning math sitting in the classroom?	3.25
Would you like to learn math moving and running like this?	5

Table 3 Day 2 Game Survey Results

Student Survey Results and Student Debriefing

Students felt they learned math by playing the game and one student stated: "I learned math playing the game, like the formula for volume." Students indicated they enjoyed playing the game and would play the game again but wanted "more teams" and a time constraint to make the game "more fun". Students preferred learn math moving and running like they were able to do in the game as opposed to learning math in the classroom. Students also asked for navigation buttons on the hoodies so they could go back and forth between questions and hints.

Observations

Students on both teams started by looking for shapes in the gameplay area. The team of girls was fascinated by the game and one of them said she wanted pink sweatshirts ("How did you do this? Let's make them in pink"). This was the second time there was focus on

the aesthetics of the hoodie. One hoodie malfunctioned displaying strange symbols and numbers, which caused one of the girls to change to another hoodie. Their math challenges consisted of trying to understand what a volume of 27 cubic feet could look like, and they thought it should be a cube instead of a prism. The 12" dowel helped students get away from so many exact measurements and increased the flow of the game. Even without the measuring tapes though, teams spent a very long time on the first question, six minutes or more trying to get exact measurements with the 12" dowel. Researchers had to prompt teams to take a risk, as the teams were fearful of the 10-second penalty.

Researchers found three modifications that would make the game more engaging; a) The first was the need to add a time constraint to questions to achieve flow (See Figure 15) in game play; b) the second was the need to model problem solving using estimation skills on one problem first, while finding an object associated with the question, and c) the need to have a one - on-one walkthrough with student teams on the first question they attempted to solve, in order to make sure students know how to play and are comfortable with the game mechanics, hoodies and to answer any questions they may have before the game starts.
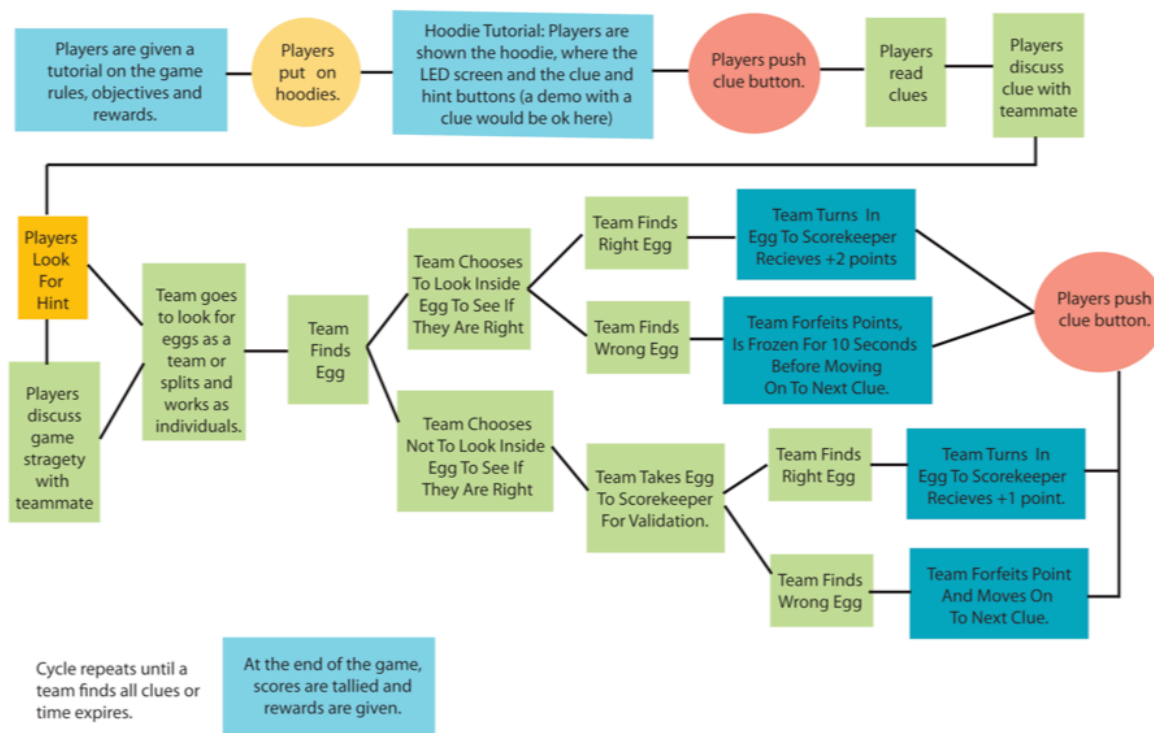
Figure 15 *Math Scavenger Hunt* Game Flow Chart

What We Learned

Students used the dowels much like the measuring tape trying to find exact measurements by moving the dowel end over end and adding the turns before multiplying by 12.

We also learned that a more defined game area boundary was needed for players to clearly see objects in the game play area and the game play area as a whole.

8.3. Southbridge Study Math Scavenger Hunt Game Day 3 - 6/6/14

Game Design Iteration based on Day 2 Study

Based on the student debriefing and researchers observations, several game design iterations were made. The game area was condensed and better defined; modeling gameplay was added before the start of the game, and last, a four-minute time limit component was added to each question. All other components of the game stayed the same as the previous study.

Game Survey Results Day 3 - 6/6/14

Question	Average
How much did you enjoy this game?	4.5
Did you use your math by playing this game?	4.25
Do you think you learned math by playing this game?	3.5
Would you play it again?	5
How Challenging was this game?	3
How much do you like learning math sitting in the classroom?	2.25
Would you like to learn math moving and running like this?	4.75

Table 4 Day 3 Game Survey Results

Student Survey Results and Student Debriefing

Overall, students enjoyed the game and would play again. One student stated, "The game was too hard." While another student said, "It was good practice." More students felt they used math than learned math by playing the game. One student commented, "I learned that real world things can actually be used to measure" and another student said, "I learned I'm going to use math to do things in life outside of the classroom." Students preferred learning math running and playing games like this compared to the classroom. Students said the hoodies were too warm and wanted the technology to be more "built in" and less noticeable (probably because of exposed wires and connections).

Observations

Overall, students were fairly positive about the game. However, students were not on the same four - minute intervals across teams, and the game would be more balanced if the time were synchronized via a centralized server. Attempting to synchronize time via standalone

technology without WiFi, was challenging. Researchers also noted a day of exploration and experimenting in the play area might be beneficial to the students.

What We Learned

Time intervals would be synchronized better through technology instead of through observers timing the game. Students conceived the time difference as a game imbalance and felt the game was unfair in that regard.

8.4. Southbridge Study Math Scavenger Hunt Game Day 4 - 6/16/14

Game Design Iteration Based on Day 3 Study

Based on the previous playtest, we adjusted the game timing by adding a time notification from the observer keeping time. All previous game play remained unchanged.

Game Survey Results Day 4 - 6/16/14

Question	Average
How much did you enjoy this game?	3.5
Did you use your math by playing this game?	3.25
Do you think you learned math by playing this game?	2
Would you play it again?	2.75
How Challenging was this game?	2.75
How much do you like learning math sitting in the classroom?	2.75
Would you like to learn math moving and running like this?	3.75

Table 5 Day 4 Game Survey Results

Student Survey Results and Student Debriefing

The 7th grade students indicated they enjoyed playing the game and would play the game again but felt the game was "too easy" and "unfair." Students felt they used math more than they learned math. One student stated, " I did not learn math but I did practice my math skills." One

student felt the game was not "fair" because of technical issues with the hoodie and time constraints. The survey suggests the students preferred learning math running and playing games like this compared to the classroom. The students said the hoodies were "too hot" but liked "the technology on the arm."

Observations

One student was using deductive reasoning to find objects instead of estimation skills. One team had difficulty with clues and showed frustration with the time limit, hoodie button operation and not being able to at least "see" if they were right.

Students computed very little on paper compared to the previous 6th graders, and this was seen as a plus by the researchers. There needs to be a way to display who is winning so each team can see where they stand. Adaptable question difficulty would make the game more engaging for all players.

Game Design Iteration for Future Studies

A time limit was added to each clue to help the flow of the game since the previous round of game testing; however, there needs to be a way to vary the level of difficulty of each clue for the teams to want to continue to play. If a clue is easy for one team, then the clue needs to increase in difficulty for the next round. If the clue is too hard for one team, then the clue needs to decrease in difficulty for the next round.

8.5. Combined Student Debriefing for all Iterations

After playing the *Math Scavenger Hunt* game, students participated in a debriefing where researchers asked "how they liked the game, if they thought they learned or used any math, how challenging was the game, what would you change in the game or technology to make it a better experience and would you play again."

How did you like the game:	"I like doing math, it was fun. (6)" "Liked being able to look and move around. (8)"
Did you learn any math:	"I learned a little math playing the game. (4)" "I learned math playing the game like the formula for volume. (2)" "Learned real world things can be used to measure. (3)" and learned "you're gonna use math to do things in life. (2)"
Did you use any math:	"It was good practice. (5)" "I used math playing the game. (12)"
How challenging was the game?	"It was challenging. (6)" "The game was easier with the hints. (4)" "Game was too hard. (2)" "Game was too easy. (3)" "The game was just right. (4)"
What would you change in the game to make it better?	"Having more teams would be more fun (10), and if there was a time constraint (4), so that they would have to go faster, that would be good."
What would you change in the technology to make it better?	"The hoodie is cool. (3) I like wearing the technical gadget. (4)" "Need buttons for navigation. (8)" "Hoodies were too hot.

	(8)" "Liked the technology on the arm. (12)" "Make the technology less noticeable and more built in. (10)"
Would you play again?	"I would play again if game was "fair" (2) and "I would play again. (12)"

**Table 6** Coding of Students' Open-Ended Responses to all CyberHoodie Iterations.

Note: A total of 16 students, eight girls and eight boys played the game. Number in parentheses is equal to the number of students who mentioned that idea, in similar words.

Question	First Study-- 4th grade	Second Study -- 6th grade	Third Study -- 6th Grade	Fourth Study -- 7th grade
How much did you enjoy this game?	4.75	4.75	4.5	3.5
Did you use your math by playing this game?	4.75	4.75	4.25	3.25
Do you think you learned math by playing this game?	3.5	3.5	3.5	2
Would you play it again?	5	4.75	5	2.75
How Challenging was this game?	3.5	4	3	2.75
How much do you like learning math sitting in the classroom?	2.5	3.25	2.25	2.75
Would you like to learn math moving and running like this?	4.75	5	4.75	3.75

Table 7 Survey Results of all CyberHoodie Iterations

What We Learned

An analysis of the survey trends (See Table 8) indicates game design iterations impacted student's experiences. Students enjoyed playing *Math Scavenger Hunt* when the questions were related to their skill level. When clue difficulty fell above or below student's skill level, student enjoyment decreased. The trend shows as game challenge decreases, student's desire to play again decreases. When the game challenge increases, student's desire to play again increases even as enjoyment decreases.
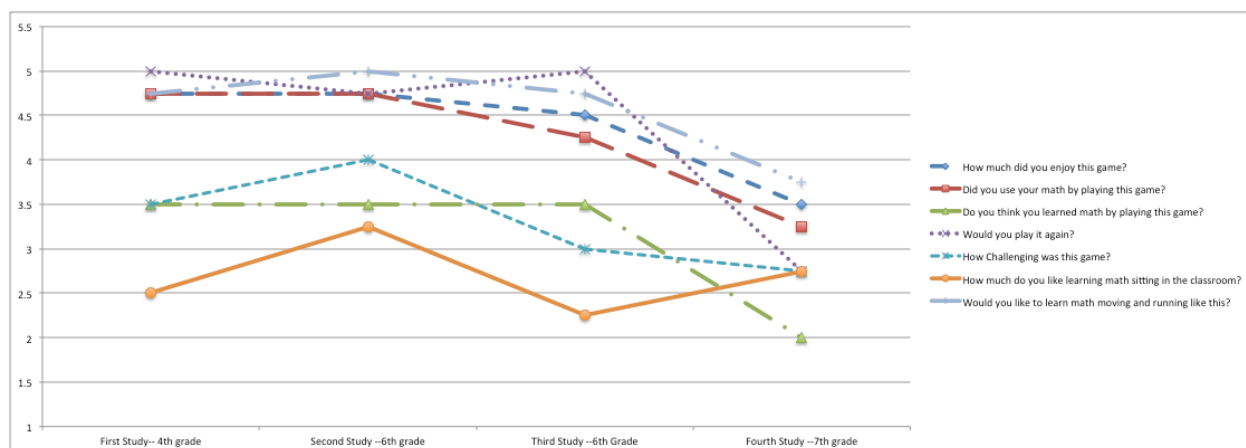
Table 8 Survey Trends

Table 8 also shows the trend in student's learning preferences by grade level. As the grade level increases, student's desire to run and play decreases even as desire to learn math sitting in the classroom remained static. Future studies involving a larger number of students are needed to validate all the trends discussed.

After addressing the student feedback, we focused on developing the technology to adapt to individual student skill level, data collection and assessment. We approached the idea of adaptability by adding technology including Wi-Fi, a database, RFID readers and tags. Adding those components would allow for the creation of software to keep time, adapt to individual student's skill level and afford immediate personal feedback to the students. Using technology to add an instant feedback component to the gameplay may increase student engagement and benefit the flow of the game by decreasing interruptions from an outside feedback source. We also learned in order to assess learning gains; a pretest and post-test should be developed and administered in future studies.

Combining technology and traditional outdoor games shows efficacy in student's math skills as students were able to problem solve on the move in an engaging environment much different than the traditional classroom. Students showed a motivation to practice math, if not learn math, by playing the game and overwhelmingly stated they would like to play again. Students are naturally inquisitive and enjoyed exploring the gameplay area while practicing their math skills. This research shows how physical math games could be integrated in schools to teach and reinforce math estimation skills in middle school students.

Based on the survey results and student feedback, we changed the wearable CyberHoodie design by compressing the components of the CyberHoodie into a device to be worn on the wrist, the CyberWatch. Dr. Arroyo assembled a team of graduate and undergraduate students, which included interactive media and game development, computer science and engineering majors to design and build the hardware and software necessary for this technology iteration.

9. From CyberHoodie to CyberWatch

The CyberWatch Undergraduate IQP (Interactive Qualifying Project) team's major goal "was to redesign the CyberHoodie into a small wearable device for the wrist (See Figure 16) that was more appealing, safer, and less prone to damage.
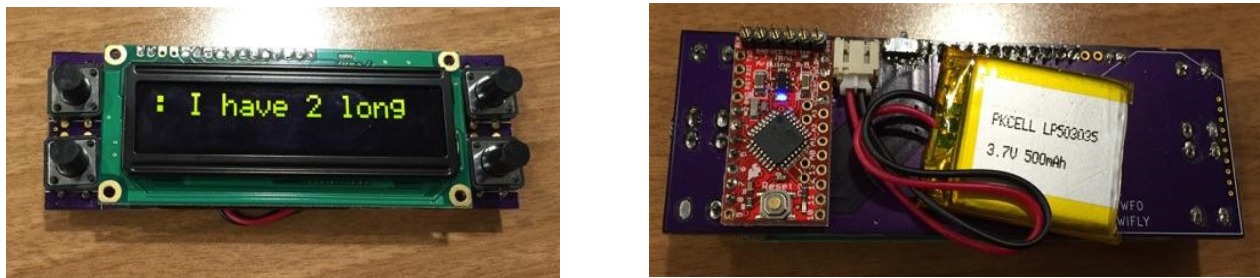
Figure 16 First CyberWarch Prototype (front and back)
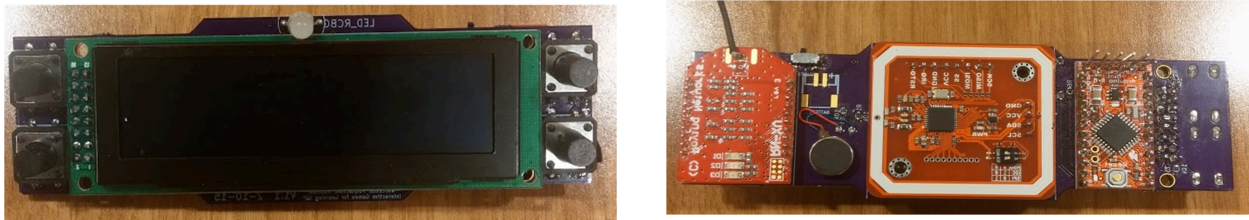
Figure 17 Second CyberWatch Prototype (front and back)

The team hypothesized that the use of this more attractive and smaller design was intuitive to younger students as well as sparked student's interest in the games being played, and technology in general. They concluded that their design would be more accommodating in that it would fit a broader range of students, without restrictions of age or body size. By upgrading the design they were able to replace multiple parts including the Arduino, Lilypad, power regulator and board to map the connection from the WiFly to the Arduino Lilypad with an Arduino pro-mini and an all-inclusive main board. This allowed for the design to become much smaller and more manageable in the hands of elementary students.

For the second prototype (See Figure 17) the team modified the original design to accommodate all of the necessary components for the more complicated "Estimate It!" game. This meant reprinting new boards, and recreating the CyberWatches with new components. This game also requires the server system to work so there was a significant amount of time spent designing that system. They created a functional server to transfer necessary game information between the server and devices. They also created a user interface that allows for the creation, setup and monitoring of games called a teacher panel.

In the final design stages the team worked towards an implementation they believed would be more versatile to a large number of games. In changing the whole design to revolve around a set of responses, a step-by-step progression for a game, they designed a system that

should in theory allow for the easy creation of any kind of game, where the game is defined as a

sequence of states, and transitions between states upon specific events. New games have the

potential to use any of the current components: an NFC reader, pixel-based LED display, buzzer,

and RGB LED light.

To adapt the game mechanics to the new technology design, I created a finite state

machine (See Figure 18 and 19) for the latest game iteration *Estimate IT! Adventure of the Kon*

Tiki, to show all states of gameplay, which includes a special nomenclature for different kinds of
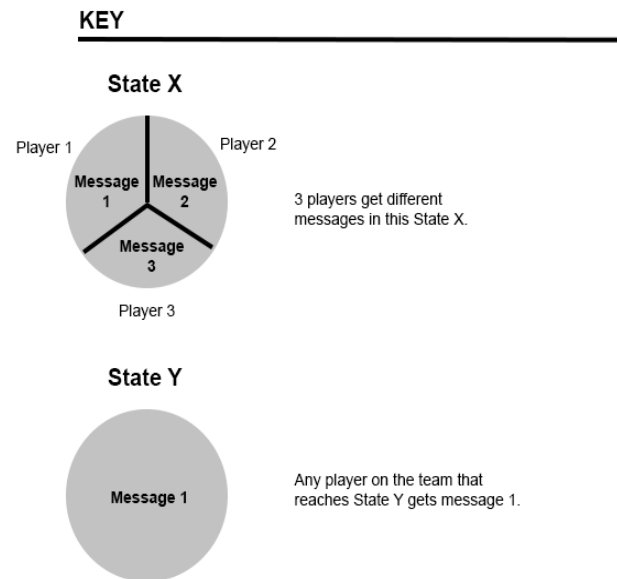
simultaneous behavior for students within the same team, as specified in Figure 18.

Figure 18 *Estimate IT!* Finite State Machine Key

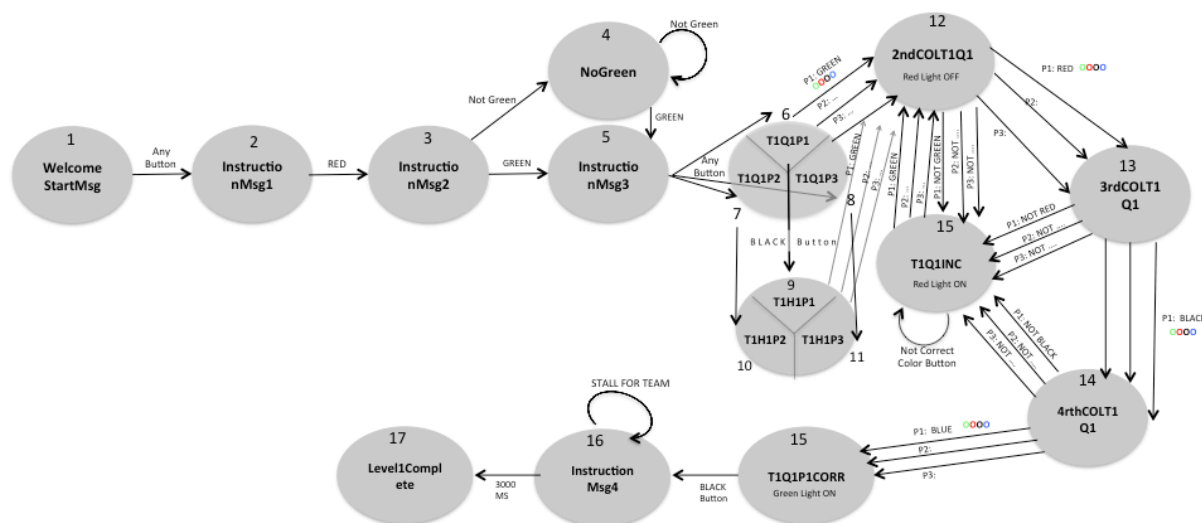**Estimate IT! Finite State Machine Level 1**

Figure 19 Estimate IT! Finite State Machine Level 1

With the addition of the finite state machine, programmers, hardware engineers and game designers can visualize the game working in every state. Having a visual model makes it easier for any member of the team to identify possible issues before they arise and address them, with this file consisting of keywords for the messages that should be displayed: a separate file contains each of the messages specification, such as the question that corresponds to T1Q1P1. This visual hierarchy of game states from both user input and computer response will allow educational game designers to design games for the CyberWatch in the future in this same form.

10. *Estimate IT!* - Latest Game Design Iteration and Study

The latest game design iteration *Estimate IT! Adventure Island - Treasures of the Kon-Tiki* is a measurement estimation and math sense game for 4th – 6th grade students. The study includes a pretest (See Appendix B) and post-tests (See Appendix C) to determine learning gains and a student survey (See Appendix D), which measures student's motivation. The learning objectives include correct measurement estimation and basic geometry identification based on

Common Core standards. Iterating on previous studies, students were given an unmarked 12"

dowel as a measurement estimation tool. Players can locate the correct objects by using several

different strategies: the measurement tool, preconceived knowledge and trial and error object

size comparison. Using 3D shapes of various sizes as the hidden objects, the game can be played

in any location where students have the room to explore. Based on what we learned from

pedagogical research, we designed an embodied math game that uses both collaborative and

cooperative methodologies. In the game's story, players act as a team of explorers seeking to

find the lost treasure of the *Kon Tiki,* which is loosely based on historical events.

The following is the level one narrative:

"You and your fellow adventurers are about to set out to find the treasures of the

Norwegian expedition raft, the Kon-Tiki that sunk near Easter Island in 1947. Before you begin

your adventure, you must find the supplies you need to make the trip. The supplies you need are

hidden inside different shapes in the play area. Find the shape you are looking for, tag it with

your CyberWatch to make sure you've found the right one. When you find the right shape, take

the shape back to the starting area. Once every member of your team has found the right shape

and taken the shape back to the starting area, your team can progress to the next level. You and

your fellow adventurers will have 5 minutes to find each object. When you are told to start, press

the red button to begin your quest. Your quest is to find: Basic Geometric Shapes"

Estimate IT! has three levels of gameplay. Level one introduces basic geometric shapes,

measurement estimation and game play narrative through collaboration, where players in teams

are given individual tasks to complete to help their team succeed students have to cooperate in

different tasks to achieve their common goal, and this may involve helping each other as more

expert team players finish first). Level two builds on level-one content and changes the game

dynamics from cooperation to collaboration, where every member on the team works together to find the same common object. Level three or the "mastery level" is an individual challenge combining learning goals from level one and two.

Knowing that not all students perform well in groups, the game was designed to balance collaborative, cooperative and individual learning goals. The third level was added to balance the group dynamic by giving the student the opportunity to progress in the game solely by his or her own effort.

Level one gameplay is based on the collaborative learning methodology where members of a team work with each other to ensure the success of the group. In level one, the CyberWatch displays specific clues (See Figure 19) for each player on all three teams. For example, the LED will display the following message to a player at the start of the game. *"Find a cube with a 6" side"*. Hint 1: *I have 6 equal sides*. Hint 2: *I am cube: a box with equal sides, each side measuring 6" long.*

Level two is based on the cooperation style of learning where the whole team works together to complete the same goal, which is to find a specific object. The CyberWatch displays the same clue for each member on a team. For example, the LED will display the following message to a player at the start of the game. *"Find a rectangular prism with a 4" side"*. Hint 1: *I am also a cuboid.* Hint 2: *I have 6 faces that are rectangles.*

Level three is an individual competition allowing students to demonstrate subject mastery against the clock. Individuals will compete to find the most shapes in the shortest amount of time. The player who finds the most in the shortest amount of time wins the game.

The three levels are divided into 20-minute blocks of time so game levels can be played during a single class period. When technology permits, additional dynamic game mechanics will

be added to the game. For example, if you have one team of high achieving students that begin to dominate the game, a "quicksand" mechanic can be added to slow down the team giving other teams the opportunity to catch up with the team of high achievers. For instance, the following is an example of the CyberWatch response to teams with advanced players: The CyberWatch buzzes to draw the players attention, flashes red and displays a message to the player that reads, "Oh, no! You are stuck in quicksand. You must wait for a member of you team to tag you before you can move. Simultaneously, team member x's CyberWatch buzzes and flashes red after which player x receives a message from the server reading, "Help! A member of your team is stuck in quick sand. Answer the following question correctly to help them. "Which one of these shapes is not a parallelogram? A. Square B. Rhombus C. Sphere D. Rectangle."

We consider *EstimateIT!* to be a viable learning tool and through iterations seek to build a database of clues based on Common Core standards, refine the game mechanics and show learning gains.

11. Conclusion

In considering games as learning tools, Bereiter and Scardamalia (1989) argued, "games create a 'cycle of expertise'." Many educational games try to create a cycle of expertise for the players; however, many times the outcome is mere rote memorization. How do you create a cycle of expertise for players without the game becoming stale and before players disengage? One possibility is creating replay ability by affording students problem posing. A study in ITS (Arroyo and Woolf, 2003) examined students as both consumers and producers of knowledge related to mathematical problem solving and problem posing. With guidance from teachers, students researched animal facts and created new mathematical word problem adventures in *Animal Watch* which became part of the ITS content. The authors discovered students felt pride

in their own creations, which in turn created an intrinsic motivation for students to learn through problem creation.

While video games have been lauded as viable learning tools, the same cannot yet be said for wearable technology since wearable technology is new to the education sector. As wearable technology moves into the educational sector, many questions need to be addressed. Questions such as, "Why would wearable technology be more viable than a smartphone or tablet as an educational tool? And, "Does wearable technology promote learning or act as a distractor to the student?" I argue, wearable technology affords students a new learning tool that would be viable in almost all classrooms. One main consideration of this device as a viable tool for learning in the classroom is the cost. The latest iteration of the CyberWatch in the prototype phase costs significantly less than the majority of commercial wearable and mobile devices on the market, even when not mass-produced. Another consideration for the device is intuitive interaction between the student and the device and the physical sensation associated with pushing buttons instead of flat screens. Security was also taken in to account when designing this technology. The CyberWatch connects to a dedicated local server and no user data is stored on the device. Lastly, instead of carrying around a device, wearable technology affords students the freedom to use both hands while playing increasing engagement in the game. In addition to cost and mobility, current technology supports a database that outperforms traditional data collection allowing for advanced data mining and can be used to develop other games, or research deeply how students interact with games, toward a continuous cycle of improvement.

Designing curriculum-based games can be a daunting task without an inclusive educational game design framework, which is a framework incorporating all components of a good educational game, such as a pedagogical foundation, game mechanics aligned to learning

goals and a dynamic system. Defining the pedagogy before the game design process creates design boundaries that better define the game. Many pedagogic theories exist and arguments in favor of using one over the other or a combination of many are too many to name. By comparing Constructivism pedagogy to Instructivism pedagogy, different game design boundaries appear. Constructivism would afford player choice, exploration and schema building. In the same context, Instructivism would afford player passivity, repetition and provide the subject matter expert (SME) the opportunity to construct a basic framework of knowledge in the players mind.

The educational game design framework should also include expert teachers, game developers and students. Since game design is a cyclical design where testing follows design and redesign or iteration follows testing.

Having an educational game design standard would streamline the development process and increase consistency in educational games across the board.

Another advantage is that using e-textiles in physical learning math games may serve as a better assessment of student's math skills than standardized testing through immediate evaluation of student's real world problem solving skills. Immediate feedback for both the teacher and student afford opportunities for correction and instruction where as standardized tests or standardized-tests based software do not. Players evidence their knowledge or lack of it in a much more obvious way, in a physical way that is easy to note.

Last, several purposes of adaptivity (personalization) in an educational game can be mentioned: to improve (the efficiency of) learning (gains); to improve transfer of knowledge to situations outside the gaming context; to optimize challenge, fun, etc. for the learner; to optimize a learner's metacognitive skills such as self-regulation, planning and monitoring; to optimize

learners' collaborative skills." (Vandewaetere, M., Cornillie, F., Clarebout, G., & Desmet, P., 2013).

Barriers to Adoption

In the Games and Learning study (2014), teachers list insufficient time as a barrier to adopting video games as learning tools in the classroom. Time constraints were used in the design process of *Estimate IT!* to address this very problem. Almost half of the teachers surveyed, 44% identified high cost as a barrier to adoption. Traditional teachers were not prepared to embrace technology in the early 90's and the integration of technology in education suffered as a result (Moeller, 2011). Research concerning educational games in the classroom has increased as the number of teachers who adopted technology increased. The teachers of today are tech savvy; technology integration is second nature to them. In Takeuchi and Vaala's (2014), "Level up learning: A national survey on teaching with digital games", 74% of teachers reported using digital games in the classroom. The number of teachers using digital games in the classroom reiterates the need for educational game design study and creation. As teachers pointed out in Takeuchi's survey (2014), "80% of digital game-using teachers wish it were easier to find curriculum-aligned games, and just 39% believe that a sufficient variety of such games even exist."

Two barriers to adoption are how games are delivered to students and tracking students' performance in game (Torrente, 2009). Of the majority of educational games, 72 % are delivered to students through computers, interactive whiteboards and tablets (Games and Learning, 2014). As the commercial wearable device market grows, educational applications of wearable devices will also grow.

Future Research

Wearable technology has yet to enter the education sector; however, I am sure companies around the world are trying to make that happen. As wearable technology enters the education market, holistic views of various devices and applications will allow consumers to identify wearable technology that meets or exceeds adopter's expectations.

Estimate IT! Pre-test page Future research should address: pedagogical foundations for educational games using wearable technology, game design iterations based on student's feedback, scaffolding as a tool for increasing student's math efficacy and learning gains through longitudinal studies following students from the 4th grade to the 6th grade. Researchers should also test the wearable technology determining the positive and negative affects of buzzers, LED lights, text readability and overall comfort.

After the findings of this research and my overall experience of studying students using wearable technology, I firmly believe that wearable technology and software applications developed for this technology will change education as an institution, by focusing on catering to the needs of the individual learner at any time and in any location, through physical and kinesthetic experiences that go beyond the experience of a student in front of a screen with a keyboard and mouse.

References

Ahmad, M., Rahim, L. A., & Arshad, N. I. (2014, June). A review of educational games design frameworks: An analysis from software engineering. In *Computer and Information Sciences (ICCOINS), 2014 International Conference on* (pp. 1-6). IEEE.

Andriessen, J., Thieme Hennis, W., & Veen. (2010) P. D. V. D3. 2–Pedagogical report.

Arroyo, Ivon, Imran A. Zualkernan, and Beverly Park Woolf. (2011) "Hoodies and barrels: Using a hide-and-seek ubiquitous game to teach mathematics." Advanced Learning Technologies (ICALT), 2011 11th IEEE International Conference on. IEEE press.

Arroyo, I., Woolf, B.P., Burleson, W., Muldner, K., Rai, D., Tai, M. (2014) A Multimedia Adaptive Tutoring System for Mathematics that addresses Cognition, Metacognition and Affect. International Journal on Artificial Intelligence in Education. Special Issue on "Landmark AIED Systems for STEM Learning". Springer.

Bruffee, K. A. (1995). Sharing our toys: Cooperative learning versus collaborative learning. *Change: The Magazine of Higher Learning*, *27*(1), 12-18.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of educational psychology*, *88*(4), 715.

Driscoll, M. (2000). *Psychology of Learning for Instruction.* Needham Heights, MA, Allyn & Bacon.

Games and Learning.org (2014). Teachers Surveyed on Using Digital Games in Class. Retrieved February 16, 2015, from http://www.gamesandlearning.org/2014/06/09/teachers-on-using-games-in-class/.

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE)*, *1*(1), 20-20.

Gee, J. P. (2005). Good video games and good learning. In *Phi Kappa Phi Forum* (Vol. 85, No. 2, p. 33). The Honor Society of Phi Kappa Phi.

Gee, James Paul. "Why are video games good for learning." *Unpublished manuscript. Retrieved* 23 (2007).

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning*, *29*(3), 207-219.

Gokhale, A. A. (1995). Collaborative learning enhances critical thinking.

Hunicke, R., LeBlanc, M., & Zubek, R. (2004, July). MDA: A formal approach to game design and game research. In *Proceedings of the AAAI Workshop on Challenges in Game AI* (p. 04-04).

Johnson-Glenberg, M. (2012, May 16). How Can Embodied Learning Help Students? - Getting Smart by Guest Author - edchat, edreform, EdTech. Retrieved January 12, 2015.

Ke, F. (2008). A case study of computer gaming for math: Engaged learning from gameplay?. *Computers & Education*, *51*(4), 1609-1620.

Kebritchi, M. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education*, *51*(4), 1729-1743.

Klopfer, E., Perry, J., Squire, K., Jan, M. F., & Steinkuehler, C. (2005, May). Mystery at the museum: a collaborative game for museum education. In *Proceedings of the 2005 conference on Computer support for collaborative learning: learning 2005: the next 10 years!* (p. 316-320). International Society of the Learning Sciences.

Lee, C. D., & Smagorinsky, P. (Eds.). (2000). *Vygotskian perspectives on literacy research: Constructing meaning through collaborative inquiry*. Cambridge University Press.

Lui, M., & Slotta, J. D. (2013). Immersive simulations for smart classrooms: exploring evolutionary concepts in secondary science. Technology, Pedagogy and Education, 1-24.

Magerkurth, C., Cheok, A. D., Mandryk, R. L., & Nilsen, T. (2005). Pervasive games: bringing computer entertainment back to the real world. *Computers in Entertainment (CIE)*, *3*(3), 4-4.

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive science*, *5*(4), 333-369.

Millstone, J. (2012, May). Teacher attitudes about digital games in the classroom. In *The Joan Ganz Cooney Center at Sesame Workshop*.

Moeller, Babette & Reitzes, Tim. (2011) Education Development Center, Inc. (EDC). Integrating Technology with Student-Centered Learning. Quincy, MA: Nellie Mae Education Foundation.

Rice, J. (2007). Assessing higher order thinking in video games. *Journal of Technology and Teacher Education*, *15*(1), 87-100.

Rockwood, H. S. III (1995a). Cooperative and collaborative learning. *The national teaching & learning forum,* 4 (6), 8-9.

Rockwood, H. S. III (1995b). Cooperative and collaborative learning. *The national teaching & learning forum,* 5 (1), 8-10.

Roschelle, J.M., Pea, R.D., Hoadley, C.M., Gordin, D. N, Means, M.N. (2000) Changing How and What Children Learn in School with Computer-Based Technologies. The Future of Children. Vol. 10, No. 2, Children and Computer Technology (Autumn - Winter, 2000), pp. 76-101. Princeton University.

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International journal of instructional technology and distance learning*, *2*(1), 3-10.

Slavin, R. E. (1990). Cooperative Learning. New Jersey: Prentice-Hall.

Slavin, R. E. (2011). Cooperative learning. *Learning and cognition in education*, 160-166.

Slavin, R. E. (2014). Cooperative learning in elementary schools. *Education 3-13*, (ahead-of-print), 1-10.

Slavin, R. E. (1980). Cooperative learning. *Review of educational research*, *50* (2), 315-342.

Squire, K., & Jenkins, H. (2003). Harnessing the power of games in education. *Insight*, *3*(1), 5-33.

Takeuchi, L. M., & Vaala, S. (2014). Level up learning: A national survey on teaching with digital games. New York: *The Joan Ganz Cooney Center at Sesame Workshop.*

Torrente, J., Moreno-Ger, P., Martínez-Ortiz, I., & Fernandez-Manjon, B. (2009). Integration and Deployment of Educational Games in e-Learning Environments: The Learning Object Model Meets Educational Gaming. *Educational Technology & Society*, *12*(4), 359-371.

Vandewaetere, M., Cornillie, F., Clarebout, G., & Desmet, P. (2013). Adaptivity in Educational Games: Including Player and Gameplay Characteristics. *International Journal of Higher Education*, *2*(2), p106.

Wilson, L. (2009). Best practices for using games & simulations in the classroom guidelines for

K - 12 educators.

Zualkernan, I. (2011). Exploring problem posing as a pedagogical device in the context of

wearable, tangible and ubiquitous game-based learning. *INTED2011 Proceedings*, 4999-

5008.

Zualkernan, Imran A. (2012). "Using a Pleasure Framework to Critique Tangible Learning

Games." *Advanced Learning Technologies (ICALT), 2012 IEEE 12th International*

Conference.

Appendix A Usability Study Survey

What is your first name? _____   **What team were you in?____**

How much did you enjoy playing this game? (ENJ)

Not at all   Sort of   Very much
1   2   3   4   5

Did you use your math by playing this game? (MATH)

Not at all   Sort of   Very much
1   2   3   4   5

Did you learn any math by playing this game? (MATH)

Not at all   Sort of   Very much
1   2   3   4   5

Would you play it again? (INTRINSIC)

Never Again   Maybe   Definitely
1   2   3   4   5

How challenging was this game? (CHALLENGE)
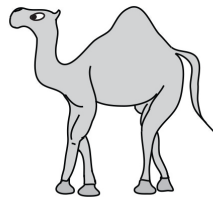
Not at all   Sort of   Very much
1   2   3   4   5

Appendix B *Estimate IT!* **Pre-Test**

Name _____

Circle the best unit of measurement for the pictures below.

1. Height of camel

- 7 feet
- 9 inches
- 11 yards

2. Length of key

- 2 yards
- 7 feet
- 4 inches

3. Circle the name of the shape below.
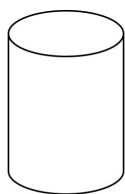
Cylinder

Rectangular Prism

Cone

Sphere

4. Circle the name of the shape below.
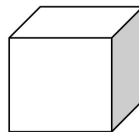
Cube

Rectangular Prism

Cone

Sphere

5. Circle the shapes that have less than 10 edges.
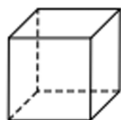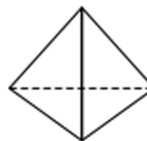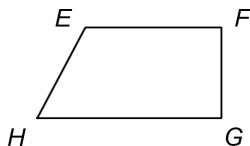
Cube   Square   Triangular   Triangular
              pyramid   prism   pyramid

Estimate IT! Pre-Test page 2

First name _____

6. Elsa drew the quadrilateral shown below.

Which angle appears to be acute?

A. angle *E*
B. angle *F*
C angle *G*
D angle *H*

7. Renato has dominoes that are each 3 inches long, as shown below.
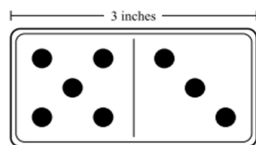
When he puts 2 dominoes end to end, they look like the picture below.
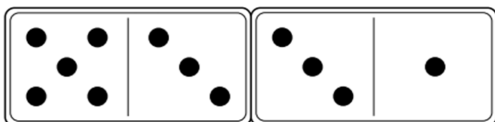
Renato puts 8 dominoes end to end. What is the total length, in feet, of Renato's dominoes?
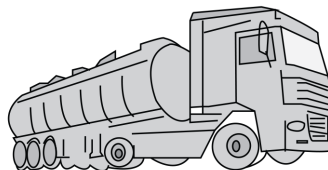
Appendix C *Estimate IT!* **Post-Test**

Name _____

Circle the best unit of measurement for the pictures below.

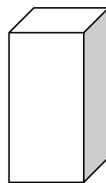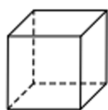| 1. Height of building	2. Length of truck
• 5 feet • 12 yards • 15 inches	• 25 inches • 8 feet • 10 yards
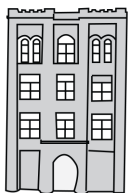
3. Circle the name of the shape below.
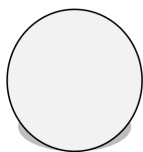
Cube

Rectangular Prism

Cone

Sphere

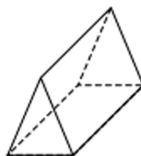4. Circle the name of the shape below.

Cube

Rectangular Prism
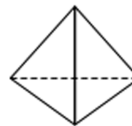
Cone

Sphere

5. Circle the shapes that have 5 faces.
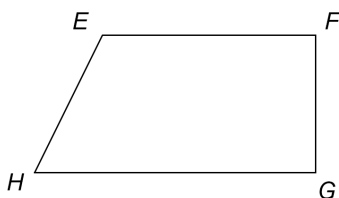
Cube   Square   Triangular   Triangular
              pyramid   prism   pyramid

Estimate IT! Post-test page 2

First name _____

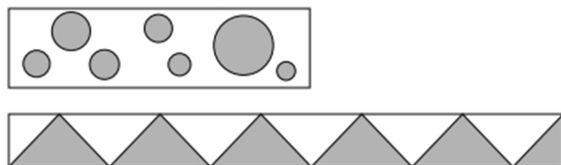6. Elsa drew the quadrilateral shown below.

Which angles appear to be right angles?

A. angles *E* and *F*
B. angle *F* and *G*
C angle *G* and *H*
D angle *H* and *E*

7. Wendy has two pieces of ribbon, as shown below.

To the nearest inch, which of the following is closest to the total amount of ribbon Wendy has?

Appendix D *Estimate IT!* Post-Test Survey

What is your first name? _____   What team were you in?____

How much did you enjoy playing this game? (ENJ)

Not at all   Sort of   Very much
1   2   3   4   5

Did you use your math by playing this game? (MATH)

Not at all   Sort of   Very much
1   2   3   4   5

Did you learn any math by playing this game? (MATH)

Not at all   Sort of   Very much
1   2   3   4   5

Would you play it again? (INTRINSIC)

Never Again   Maybe   Definitely
1   2   3   4   5

How challenging was this game? (CHALLENGE)

Not at all   Sort of   Very much
1   2   3   4   5