DIGITALLY CURIOUS: A QUALITATIVE CASE STUDY OF STUDENTS’
DEMONSTRATIONS OF CURIOSITY IN A TECHNOLOGY-RICH
LEARNING ENVIRONMENT

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Dissertation Prepared for the Degree of
DOCTOR OF PHILOSOPHY

UNIVERSITY OF NORTH TEXAS
August 2011

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Curiosity is an important construct for educators as it is connected with knowledge and higher-order thinking, goal-oriented behavior, motivation, and persistence. It is also negatively correlated with boredom and anxiety. While research documents this strong connection between learning and curiosity, no studies existed exploring curiosity in a technology-rich learning environment. The purpose of this study is to identify and examine whether students demonstrate curiosity in a sixth grade mathematics classroom with technology-integrated learning and if so, how and why. Technology-rich work was designed for students and included in the study to examine students’ demonstrations of curiosity while learning mathematical procedural knowledge, conceptual knowledge and problem solving knowledge. A case study methodology was used with 13 students purposefully selected from a Title I sixth grade class to participate. Data were collected from interviews using a semi-structured interview protocol and triangulated with observations and students’ reflective writings. Interviews were transcribed and coded. A total of 60 codes and four categories were identified. Three themes emerged: 1) digital play; 2) welcome and unwelcome scaffolds; and 3) action is power; power follows ideas. These themes identified ways in which students demonstrated curiosity in the sixth grade mathematics classroom and thus can inform educators.
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ACKNOWLEDGEMENTS

It is with deep gratitude to so many that I complete this study: my parents who always told me that I could do anything I set my mind to do; my husband and children whose public and private support and patience was unparalleled; my colleagues, Dr. Sheri Vasinda and Dr. Mary Jo Dondlinger, who provided expertise, encouragement and joy to the process; my students who participated in the study and willingly shared their time and their thinking; and my committee who provided encouragement and guidance.
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CHAPTER 1
INTRODUCTION

Clearly, our world today has changed dramatically from even one or two generations ago. Technology is an agent of that change, bringing distant neighbors closer, providing new avenues for competition and collaboration, and increasing productivity (Friedman, 2006; Tapscott & Williams, 2006). In general, educators have struggled to keep up with the changing demands (McLeod & Vasinda, 2009). For example, most know well some iteration of the story of time travelers from a hundred years ago who were baffled by a modern operating room, but felt at home in the classroom (Papert, 1983). Even today when almost all classrooms in the developed world have computers and Internet access, the students’ access to the computers is still low, with an average of six students per computer (OECD, 2006). Several organizations have begun to address the societal and technological changes by offering guidance for twenty-first century learning environments. One organization, the State Educational Technology Directors Association, issues research reports on national trends and creates action plans for educators. A recent report, Class of 2020: An Action Plan for Education (2008), offers specific steps for educators to follow. The first step charges educators with “ensur(ing) that technology tools and resources are used continuously and seamlessly for instruction, collaboration, and assessment.” (2008, p. 6). From this proposal, it is clear that the leaders at the State Educational Technology Directors Association perceive a strong connection between our technology-infused society and technology-rich learning.

Another organization, the Partnership for Twenty-first Century Skills, is a consortium of the United States Department of Education and eight partner corporations. This group has added
to the State Educational Technology Directors Association recommendations by creating a framework of skills that young students need as they grow to be contributing members of society (Partnership for Twenty-first Century Skills, n.d.). This framework consists of four elements:

1) Core subjects and Twenty-first century themes
2) Learning and innovation skills
3) Information, media and technology skills
4) Life and career skills

Beyond consistent technology use, this framework has a number of educational themes that tightly weave learning and technology.

As identified by Kashdan (2004) and Loewenstein (1994), one crucial element of learning with or without technology is curiosity. Curiosity is defined as a desire to know or an interest that leads to inquiry (Merriam-Webster Online, n.d.). Even with this simple dictionary definition, it is clear that curiosity is the precursor to learning (Loewenstein, 1994). While learning can happen without curiosity, it is learning with curiosity that creates a cycle of learning that fuels more curiosity and then more learning, culminating in deep and lasting knowledge (Kashdan, 2004). Curiosity is also closely related to other emotional states such as motivation (Kashdan & Fincham, 2004) that have been noted to be important to spark the learning process (Gagne, Wager, Golas, & Keller, 2005; Keller & Kopp, 1987).

While not specifically stated as curiosity, many of the elements of the framework by the Partnership for Twenty-first Century Skills point to encouraging and even developing students’ curiosity. For example the learning and innovation skills element includes a bullet point noting students should “be open and responsive to new and diverse perspectives” (Partnership for Twenty-first Century Skills, n.d.). This openness construct is an important dimension of curiosity.
Another bullet point in the learning and innovation skills element asks students to “view failure as an opportunity to learn” (Partnership for Twenty-first Century Skills, n.d.). This bullet alludes to the *persistence* that curiosity feeds, even persistence in the face of significant obstacles (Kashdan, Steger, & Breen, 2007). Finally, the life and career skills strand includes “Initiative and Self-Direction” which addresses many of the traits closely aligned to curiosity as follows:

- “Monitoring one’s own understanding and learning needs
- Going beyond basic mastery of skills and/or curriculum to explore and expand one’s own learning and opportunities to gain expertise
- Demonstrating initiative to advance skill levels towards a professional level
- Defining, prioritizing and completing tasks without direct oversight
- Utilizing time efficiently and managing workload
- Demonstrating commitment to learning as a lifelong process” (Partnership for Twenty-first Century Skills, n.d.)

These skills represent the initiative and independence in learning that are also hallmarks of curiosity (Kashdan, 2004). All of these aspects point to the importance of curiosity for learning in the new century.

Finally, because the proposed research will include students in a mathematics classroom, guidance from the National Council of Teachers of Mathematics (NCTM) is important to ensure that best practices are followed. The NCTM explicitly denotes the importance of developing students’ mathematical dispositions (NCTM, 1989). Specifically, the NCTM defines mathematical dispositions as students’ tendency to be reflective with a curiosity to explore unfamiliar mathematical problems. This curiosity about mathematical problems, while important,
is not always fostered with traditional mathematical education practices. Indeed, as students proceed through their educational career, curiosity continues to decline (Torrance, 1965).

Statement of the Problem

Curiosity has been identified as important to learning and to the type of disciplined scientific inquiry necessary for success in twenty-first century society (Friedman, 2006; Tapscott & Williams, 2006). However, our current education system does a poor job of stimulating curiosity and, in many cases, systematically suppresses it (Loewenstein, 1994; Torrance, 1965). This issue is clearly not new; however, the hyper-competitiveness of a technologically connected world has brought this issue to the forefront of the educational debate as evidenced by the work of organizations such as the State Educational Technology Directors Association, The Partnership for Twenty-first Century Skills, and the National Council of Teachers of Mathematics. Thus, the problem is two-fold:

1) Curiosity has been identified as a necessary emotional state for the type of deep learning needed for twenty-first century students, but it is not currently fostered in the educational system

2) It must be examined as to whether the technology-rich learning environments of the future, which are currently envisioned by organizations such as the State Educational Technology Directors Association and the Partnership for Twenty-first Century Skills have room to foster the necessary curiosity

It is this combination of curiosity, technology and learning which is uniquely born in the twenty-first century that is the problem of interest to this study.
A search for curiosity research that includes technology in the learning process returned minimal results. Researchers either simply allude to students’ natural curiosity about technology as a reason to use the technology in the learning environment (Ching, 2009), or claim to study curiosity within a technology-rich learning environment but measure curiosity in an inappropriate manner by only measuring the number of questions students can generate (see Rule & Barrera, 2008) or, instead, measure student engagement (Wang & Reeves, 2006). Thus, this research attempts to fill the void formed by this emerging problem. In other words, this study will examine demonstrations of student curiosity in the context of a mathematics classroom in which technology is integrated into teaching and learning.

Purpose of the Study

The purpose of this study is to identify and examine whether students demonstrate curiosity in a mathematics classroom with technology-integrated learning and if so, how and why. Of course, the use of technology in the teaching and learning process can vary widely depending on two significant aspects: 1) the access to technology and 2) the learning experiences or work students do with the technology. The access to technology is the first significant aspect and is the issue addressed by the State Educational Technology Directors Association. Overall, students in this sixth grade classroom use technology on average for half of their 90-minute mathematics class period. In this study, the classroom is equipped with a laptop cart that is dedicated for use by this teacher. There are enough laptops in the laptop cart for each student to have one during his/her time in the mathematics classroom. There are also at least two spare laptops in case one computer has issues. Other technology used, such as microphones, digital pens, headphones, and mobile devices, are plentiful enough for the work designed that students
can use these devices as needed without waiting. The technology-based work is the second significant aspect and is the issue addressed by the Partnership for Twenty-first Century Skills and the National Council of Teachers of Mathematics. During this study, students will use technology in a variety of ways, including mathematical simulations, publishing mathematics work online, creating digital mathematical products, and basic drill and practice. Corlis and Weiss (1973) have noted the importance of this type of research, stating that research in developing students’ curiosity is lacking. This statement is still true as technology-rich learning environments are still rare in public schools (OECD, 2006).

Specifically, the research questions for this study are as follows:

1. Do sixth grade students demonstrate curiosity in the mathematics classroom with technology-integrated learning? And if so,
2. How and why do sixth grade students demonstrate curiosity when learning mathematical procedural knowledge using technology?
3. How and why do sixth grade students demonstrate curiosity when learning mathematical conceptual knowledge using technology?
4. How and why do sixth grade students demonstrate curiosity when learning mathematical problem solving using technology?

Limitations and Delimitations

This study has several limitations and thus may not be generalizable to student populations. First, the study is a case study, which generalizes to theories, not populations (Yin, 2009). Further, the study sample size is too small to generalize the results. This study consisted of 13 participants at one elementary school, certainly a number far too small to represent all
students. Also, the sample demographics are not necessarily representative of the general population. This study takes place in a Title I school in a suburban town in North Texas. A Title I school is defined as one in which the majority of students meet the federal guidelines to qualify for free/reduced lunch. The study school has 61% of students who qualify for free/reduced lunch. This setting is not similar to all schools in the United States.

The fact that the study takes place in a public school creates further limitations. Attendance at the school is based on geographic zoning and thus depends on where a child lives. Because sixth grade is departmentalized at this school, all sixth grade students have the same mathematics teacher and are part of this study. Because of these reasons, there is no opportunity for random sampling or random selection of students to participate in the study. Students attend mathematics class for approximately eighty minutes each day. They are separated into three periods or blocks, a mathematics block, a language arts block and a science/social studies block. This time limit and artificially segmented content limits a natural learning context.

The political setting of the study includes a standards-driven, high stakes testing environment. Sixth grade mathematics standards called Texas Essential Knowledge and Skills (TEKS) in Texas require students to learn approximately 75% new material, on which they are tested on the state mandated assessment called the Texas Assessment of Knowledge and Skills (TAKS) in April. This is relevant because the amount of new content that students must learn to be successful on the state mandated assessment biases breadth rather than depth, a particularly challenging situation to foster curiosity.

The study also has delimitations. The access to technology in schools and the nature of technology-rich student work vary significantly. Efforts to replicate this study should pay particular attention to the type of technology-based work students complete.
Summary

Current technological trends in our society have created the need to reevaluate traditional schooling. Specifically, several organizations have offered a charge to educators to use technology in a meaningful way during the teaching and learning process. Further, with the hyper-competitiveness of today’s technological society, it is no longer sufficient to have a surface knowledge of concepts. Students must push to deep levels of learning and must have the motivation to continue to learn even after formal schooling. Thus, curiosity has become a crucial emotional-motivational state for today’s learners. This research study seeks to describe how students demonstrate their curiosity in a sixth grade mathematics classroom with technology-integrated learning.

Definitions

*Curiosity*: The emotional-motivational state and capacity of all people to actively acquire information in order to create, maintain and/or resolve gaps in knowledge

*Technology-rich learning environment or technology-integrated learning environment*: A learning environment in which technology is used by the learner as an integral part of the learning process. In other words, the teacher’s pedagogical stance is different because students have access as needed to technology. Thus, the work designed for students leverages the technology.

*Web 2.0*: Internet based platforms that provide for interactive, user-generated content. Examples of Web 2.0 platforms include blogs, wikis and podcasts.
CHAPTER 2
LITERATURE REVIEW

Curiosity has a long history of importance in educational theory, including advocates and scholars such as Dewey (1997), Bruner (1966), Piaget (1952), and Freire (2000). Additionally, more recent scholars such as Keller (& Kopp, 1987) and Gagne (& Wager, Golas, & Keller, 2005) have recognized the importance of closely related traits such as motivation. Further, scholars in other fields such as psychology recognize a renewed importance of curiosity and have recently extended the research surrounding curiosity (e.g., Kashdan, 2004; Litman & Spielberger, 2003). This research has been varied and educationally relevant, including themes such as types of curiosity, how to measure curiosity, and fostering curiosity.

Many have recognized the importance of curiosity in education because the learning with curiosity sparked is deeper and more lasting (e.g., Bruner, 1966; Dewey, 1997). However, with technology seemingly advancing the pace of change in society and fundamentally changing the way business is conducted (Friedman, 2006; Tapscott & Williams, 2006), it is important to integrate the research on curiosity with twenty-first century educational theory, especially focusing on the ways in which technology-rich learning environments affect curiosity and how, in turn, that impacts learning. A solid working definition is necessary before studying the construct.

Definition and Etymology of Curiosity

Since the time of early philosophers such as Plato and Aristotle, curiosity has demanded attention (Lowenstein, 1994; Reio, Petrosko, Wiswell, & Thongsukmag, 2006). While no formal definition evolved from this early thinking, Plato identified three aspects of curiosity. First,
curiosity was viewed as an intrinsic motivation or desire for information. Second, curiosity was seen as a passionate act. Third, curiosity was linked with an appetite for knowledge (Lowenstein, 1994). This appetite for knowledge fuels a cycle of curiosity and learning which results in deep and lasting knowledge. Twenty-first century scholars have maintained these aspects of curiosity with definitions such as “the emotional-motivational state...associated with actively acquiring information to create, maintain, and/or resolve meaningful perceptual conflicts or gaps in knowledge” (Kashdan & Fincham, 2002, p. 373) and “a desire to acquire new [information and] knowledge and new sensory experience that motivates exploratory behavior” (Litman & Spielberger, 2003, p. 75).

Berlyne (1954) further defined two types of curiosity: perceptual curiosity, which leads to an increasing ability to perceive stimuli, and epistemic curiosity, which is the drive to know that comes from gaps in knowledge. Importantly, Aristotle believed that curiosity was universal (Reio, Petrosko, Wiswell, & Thongsukmag, 2006). However, this is one aspect that is not directly stated in any definition. Thus for the purposes of this study, the definition of curiosity is a slightly modified version of Kashdan and Fincham’s (2002) definition. Curiosity is the emotional-motivational state and capacity of all people to actively acquire information in order to create, maintain and/or resolve gaps in knowledge.

Researching curiosity’s etymology exposes a lively history. Interestingly, early philosophers had an informal consensus in their thinking about curiosity. As previously noted, early philosophers such as Plato and Aristotle identified three specific aspects of curiosity that enjoyed consensus: 1) curiosity’s intrinsic and motivational desire for information; 2) curiosity’s connection with passion; 3) curiosity’s appetite for knowledge (Loewenstein, 1994; Reio, Petrosko, Wiswell, & Thongsukmag, 2006).
Since then, scholars in the early twentieth century diverged into different realms with curiosity, which led to many different definitions. More recently, William James (1890/1950) noted two types of curiosity. The first was a novelty-seeking type of curiosity that addressed exploring and enjoying novel situations. The second was scientific curiosity, which was a perceived gap in knowledge. This two-type model of curiosity is still modeled in contemporary literature (Kashdan, 2004). Early in the twentieth century, behaviorist researchers expanded the definition of curiosity by researching a variety of behaviors they defined as curiosity or exploratory behavior. These behaviors included investigatory reflex, orienting reflexes, and the tendency to seek out variation in environment. Today, these traits might be labeled as attention or exploration (Kashdan, 2004; Loewenstien, 1994).

Finally, D. E. Berlyne, through his groundbreaking research, brought some structure and consensus back to the definition of curiosity (Kashdan, 2004; Loewenstien, 1994). Figure 1 is a conceptual drawing of this etymology of curiosity.

![Conceptual Drawing of the Etymology of Curiosity](image)

*Figure 1. Conceptual drawing of the etymology of curiosity.*
In the early 1950s, Berlyne began to bring consensus back to curiosity research by proposing a structure to categorize different types of curiosity (Kashdan, 2004; Loewenstein, 1994). Specifically, Berlyne (1954) identified two dimensions of curiosity. This varied from James’s (1890/1950) definition because, in Berlyne’s view, each dimension of curiosity had its own interval span with each end of the span having a different type of curiosity. Thus, Berlyne actually identified four types of curiosity. Figure 2 includes Berlyne’s two dimensions of curiosity along with both ends of each span and the figure also includes explanatory examples.

**Figure 2.** Berlyne's (1954) dimensions of curiosity with examples by Loewenstein (1994).

In Berlyne’s view, one dimension of curiosity spans between perceptual and epistemic curiosity. Perceptual curiosity is the instinctual, exploratory behavior that is not unique in humans (Loewenstein, 1994). While not unique, humans will use perceptual curiosity because it “leads to an increased perception of stimuli” (Berlyne, 1954, p. 180). In other words, perceptual curiosity
is an imbalance (i.e., perceived gap in knowledge or novel situation) that leads to exploration (McGuire & Rowland, 1966). Epistemic curiosity is defined as a desire for knowledge and is certainly considered unique to humans (Litman & Spielberger, 2003; Loewenstein, 1994). Because this type of curiosity is specifically related to knowledge, it is of utmost interest to educators.

The other dimension of curiosity spans between specific and diversive curiosity. Specific curiosity relates to the tendency to dig deep for a particular piece of information (Litman & Spielberger, 2003; Loewenstein, 1994). It is specific curiosity that is invoked when people persevere to find an answer. Diversive curiosity is defined as the desire for stimulation. This type of curiosity has been closely related to boredom (Litman & Spielberger, 2003; Loewenstein, 1994).

Figure 2 is a drawing of the two dimensions of curiosity with each dimension spanned to the opposite extremes. Further, in each box is an illuminating example from Loewenstein (1994). The top dimension has been titled the motivational dimension. The difference in the two extremes of this dimension rest in the difference between humans’ ancient brain that connects us with other animals and is more instinctual and the modern brain that allows us to think, reason, and be purposeful (Marcus, 2008). The dimension on the left is titled the behavioral dimension. It is the dimension that is most readily displayed outwardly.

The curiosity literature also includes discussions of the difference between state curiosity and trait curiosity (Loewenstein, 1994; Reio, Petrosko, Wiswell & Thongsukmag, 2006). State curiosity is the disposition to explore in a particular situation (Loewenstein). For example, if a person is particularly interested in mathematics or is just intrigued by a certain question posed on a particular day. On the other hand, trait curiosity is the general capacity to explore
(Loewenstein). For example, if a person can become curious more easily than another person. Overall, state and trait curiosity are reciprocal and each is malleable (Kashdan, 2004; Kashdan & Fincham, 2004; Loewenstein, 1994). In other words, because curiosity feeds itself from knowledge, if a person becomes interested in a particular question and explores it fruitfully (state curiosity), that person has a higher likelihood of exploring questions in the future (trait curiosity) (McGuire & Rowland, 1966). Thus, because both state and trait curiosity interact significantly and are malleable, the measurement of curiosity does not necessarily need to differentiate between the two.

Importance and Relevance of Curiosity

The more researchers discover about curiosity, the more important and relevant it becomes to educators (Anderson, & Krathwohl, 2001; Berlyne, 1978; Bruner, 1966; Dewey, 1997; Friedman, 2006; Gagne, Wager, Golas, & Keller, 2005; Hannafin, 1981; Kashdan, 2004; Kashdan & Silva, 2009; Kashdan, Steger, & Breen, 2007; Keller & Kopp, 1987; Loewenstein, 1994; McGuire & Rowland, 1966; Ofer & Durban, 1999; Ogle, 1986; Piaget, 1952; Payne, 2005; Reio, Petrosko, Wiswell, & Thongsukmag, 2006; Scheifele, Krapp, & Winterler, 1992; Schlechty, 2002; Schmitt & Lahroodi, 2008; Stevenson & Odom, 1965). Specifically, there are five areas of particular interest to educators: 1) curiosity’s connection to knowledge and higher order thinking; 2) curiosity’s connection to motivation and persistence; 3) curiosity’s connection with goal oriented behavior; 4) curiosity’s reciprocal nature; and 5) curiosity’s antitheses of boredom and anxiety. These areas of interest are derived from a synthesis of the research and are described below.
Curiosity’s Connection to Knowledge and Higher Order Thinking

Curiosity has an important connection with knowledge and higher order thinking. In fact, researchers have identified that curiosity explains approximately ten percent of the variance in students’ achievement (Schiefele, Krapp, & Winterler, 1992). Dewey (1997) addressed curiosity’s connection with knowledge, writing that curiosity is “the only sure guarantee of the acquisition of the primary facts” (p. 31) because he believed that learning with curiosity was a deep learning that allowed for higher order thinking such as inferencing.

Schmitt and Lahroodi (2008) posit that curiosity’s first defining moment is the drawing of one’s attention to an object or topic of interest. Essentially, curiosity is the beginning of the learning process. This element is identical to Gagne’s (Gagne, Wager, Golas, & Keller, 2005) first step in his Nine Events of Instruction, gaining attention. Importantly, curiosity plays an extended role in the learning process as well. Kashdan, Steger, and Breen (2007) have found that curiosity promotes engagement, which has been identified by Schlechty (2002) as a crucial element in the learning process. Further, curiosity can be sparked when learners identify a perceived gap in their knowledge; this is expected to motivate people to learn more (Loewenstein, 1994; Schmitt & Lahroodi, 2008). Curiosity has also been directly linked to higher order thinking (Kashdan, Steger, & Breen, 2007), a skill which will be in high demand in the twenty-first century (Friedman, 2006) and which rests among the top skills on Bloom’s Taxonomy (Anderson, & Krathwohl, 2001). Dewey (1997), Berlyne (1978), Bruner (1966) and Piaget (1952) all cite curiosity as a major impetus to scientific discovery and the survival and advancement of civilization. Indeed, curiosity stimulates learning that is fast and persistent, but also learning that pulls together fragments into coherent knowledge structures (McGuire & Rowland, 1966).
While other scholars have alluded to curiosity indirectly (Reio, Petrosko, Wiswell, & Thongsuksom, 2006), they have preferred words such as motivation (Keller & Kopp, 1987) and gaining attention (Gagne, Wager, Golas, & Keller, 2005). It has been stated that curiosity is more valuable than other motivations to know because of the mutual support that curiosity has between drawing attention and the continued desire to know in spite of any practical or epistemic motivation to know (Schmitt & Lahroodi, 2008). Curiosity strengthens the tenacity to learn, deepens our interests in learning new things, and even allows for broader learning experiences as learners make connections between what is known and what is unknown (Schmitt & Lahroodi, 2008), all of which are relevant to educators as we find ways to help students assimilate the required information and knowledge.

**Curiosity’s Connection to Motivation and Persistence**

Keller and Kopp (1987) recognized the importance of motivation in the learning process. Further, Jensen (Eric Jensen, public presentation, June 23, 2009) notes that our brains are not wired to learn from random input. We must have “buy in” or a desire to know the information. Curiosity has been found by Reio, Petrosko, Wiswell, and Thongsuksom (2006) to strongly correlate with motivation. In fact, motivation has been a fundamental part of Kashdan and Silva as well as Schmitt and Lahroodi’s definitions of curiosity in their research and theory work. Schmitt and Lahroodi (2008) have also correlated curiosity with academic persistence; indeed, it has also been shown to strengthen student persistence, even when tasks are challenging or otherwise mundane (Kashdan, Steger, & Breen, 2007). Today’s standards and high stakes testing require much knowledge from students, making their motivation to learn and persistence in the face of adversity crucial to success.
Curiosity’s Connection with Goal Oriented Behavior

Students who set their own academic goals are more likely to achieve them (Hannafin, 1981). Also, Hannafin (1981) has found evaluations of student work by teachers are more favorable. This is particularly important with the sample in this study, which consists of students at a Title I school, as Payne (2005) theorizes that children from poverty need extra guidance with goal setting and goal oriented behavior. Zimmerman (2001) uses the term self-regulated learning to describe learners that “display personal initiative, perseverance and adaptive skill” (p. 1). Paris and Byrnes (1989) found that self-regulated learners “seek challenges and overcome obstacles sometimes with persistence and sometimes with inventive problem solving. They set realistic goals and use a battery of resources. They approach academic tasks with confidence and purpose.” (p. 169). Clearly, setting and working towards goals are important activities related to learning. Curiosity, which Kashdan (2004) has correlated with a strong connection to goal-oriented behavior, is a strong ally for educators.

Curiosity’s Reciprocal Nature

As noted previously, curiosity is connected with knowledge, higher order thinking, motivation, persistence, and goal setting. Clearly, curiosity is a trait in which educators must work to spark in their students. Unfortunately, Loewenstein’s (1994) research has indicated that curiosity can be short lived and even fleeting. Fortunately, curiosity has a reciprocal nature with knowledge (Kashdan, 2004). Some knowledge creates the realization that more is left to learn. This facilitates more curiosity, which leads to more knowledge (Kashdan, 2004). According to Loewenstein (1994), the main ingredient to continue the curiosity and knowledge cycle is the perception of an information gap. In other words, people must perceive that there is more to learn.
about a topic and that the information is attainable. Many teachers have used techniques such as the K-W-L chart (Ogle, 1986) to activate and sustain curiosity. A K-W-L chart asks students to list what they know (K) about a particular topic and what they want (W) to learn about that topic before the learning begins. Then, after the lesson, students revisit the K-W-L chart to list what they learned (L) about the topic. This technique is an example of ways educators can leverage the reciprocal nature of curiosity to facilitate student learning. More recent modifications of the K-W-L chart include the KLEW chart (Herschberger, Zembal-Saul, & Starr, 2008). In this modification, evidence (E) and wonder (W) are used along with know (K) and learning (L) to help students make connections to their learning, identify gaps in their knowledge, and ask strong, testable questions about the topic (Herschberger, Zembal-Saul, & Starr, 2008).

_Curiosity’s Antitheses of Boredom and Anxiety_

Learning requires attention and engagement (Gagne, Wager, Golas, & Keller, 2005; Schlechty, 2002). Further, anxiety level is negatively correlated with learning and problem solving (Stevenson & Odom, 1965). Thus, students who are bored or anxious are not as open to a learning experience and may not learn or retain all that is important. Fortunately, curiosity not only combats boredom as found by Kashdan (2004), it is also correlated with a reduction in anxiety as found by Kashdan and Silva (2009; and Ofer & Durban, 1999); further, it also encourages deep learning (Kashdan, 2004). Thus, educators can use curiosity during particularly stressful times or during mundane but necessary tasks to ensure that students are learning.
Curiosity Wanes

While curiosity is clearly important to educators and to students as they prepare themselves for their twenty-first century society, previous research indicates that curiosity wanes as students age (Torrance, 1965, 1968). Indeed, Torrance documented that students’ school environment does change with teachers of older students less likely to appreciate unusual questions from students. Torrance famously studied creativity in depth. However, curiosity came up because of the reciprocal nature of creativity and curiosity.

Torrance’s work with curiosity included the Ask-and-Guess Test (Torrance, 1965). In this test, students were shown a picture and were allowed to ask all the questions they could think of about the picture. Students were then asked to begin guessing all the possible causes of the events depicted in the picture. Finally, students were asked to list all the consequences they could foresee from the actions in the picture. By testing a wide range of students from primary to adult, Torrance maintained the hypothesis that curiosity wanes in fourth grade. This test that is widely cited in the curiosity research literature is highly subjective and is certainly dependent on a student’s interest in the picture shown. Thus, this study explores how students demonstrate curiosity on several technology based projects and using several different data collection methods.

Connecting Curiosity and Technology

Curiosity is intricately connected and vitally important in the learning process, but does not depend on technology. Certainly, curiosity existed and thrived before computers and before the Internet. However, it is controversial whether these traits thrived in schools, with scholars demonstrating that curiosity decreases markedly as students advance through school
(Loewenstein, 1994; Torrance, 1965, 1968; Vidler & Karan, 1975). Even with technology in schools, the existence and use of that technology does not guarantee that learners will use their curiosity.

As previously noted, research surrounding curiosity and technology in education does not currently exist. Research does support student-enhanced motivation with technology use as has been noted by several recent studies (Burton, 2009; Mula & Kavanagh, 2009; Rose & Dalton; 2009; Strom, Strom, Wing, & Beckert, 2009). However, motivation is an important emotional state for learning and has been closely linked to curiosity. To be clear, curiosity is not motivation and is unique and Berlyne (1960) posits that curiosity is a prerequisite to motivation. In other words, curiosity exists prior to motivation and is a precursor to educationally superior intrinsic motivation. Therefore, curiosity is an important construct to study independent of motivation for educators to understand how motivation can begin. However, the context of the environment has been found to be crucial when researching curiosity (Loewenstein, 1994; Schmitt & Lahroodi, 2008; Sternberg, 2006). Thus, the environment of this particular study is delineated in detail, including the purposeful and meaningful use of new technologies.

Summary

Curiosity is defined as the emotional-motivational state and capacity of all people to actively acquire information in order to create, maintain and/or resolve gaps in knowledge. There are five important aspects of curiosity that increase its relevance to educators: 1) curiosity’s connection to knowledge and higher order thinking; 2) curiosity’s connection to motivation and persistence; 3) curiosity’s connection with goal oriented behavior; 4) curiosity’s reciprocal
nature; and 5) curiosity’s antitheses of boredom and anxiety. Finally, curiosity and technology are connected for the learning environment of the twenty-first century.
CHAPTER 3

METHODOLOGY

The purpose of this study is to examine how and why students demonstrate curiosity in a sixth grade mathematics classroom with technology-integrated learning. This methodology chapter contains details about the sample, and the context of the study. It also outlines the data collection and data analysis procedures.

Research Questions

The research questions for this study are as follows:

1. Do sixth grade students demonstrate curiosity in the mathematics classroom with technology-integrated learning? And if so,

2. How and why do sixth grade students demonstrate curiosity when learning mathematical procedural knowledge using technology?

3. How and why do sixth grade students demonstrate curiosity when learning mathematical conceptual knowledge using technology?

4. How and why do sixth grade students demonstrate curiosity when learning mathematical problem solving using technology?

These questions explore technology-rich learning during three different types of mathematical learning: 1) learning procedural knowledge; 2) learning conceptual knowledge; and 3) learning problem solving.
Overview of Research Methods

This is exploratory research as portrayed by Schutt (2009) because curiosity research in technology-integrated classrooms is limited. One of the goals of exploratory research is to take a line of inquiry in a new direction (Schutt, 2009) as this research takes the curiosity research in another direction with technology-integrated student work. Further, it is descriptive research because this study aims to document “what is” (Knupfer & McLellan, 1996, p. 1197). It follows a qualitative case study design. Qualitative methods are appropriate for exploratory research (Schutt, 2009) and descriptive research (Knupfer & McLellan, 1996), in both cases because qualitative researchers do not begin their studies with a hypothesis to test, but begin by asking questions to discover how people think or why they act a certain way. Then qualitative researchers try to make generalizations. Detailed descriptions and justifications of these methods are offered in this chapter.

Participants

The participants are drawn from all sixth grade students at an elementary school in a North Texas suburban town. The setting is a Title I school with 61% of all students on free or reduced lunch. Overall, there are 56 sixth grade students with a gender breakdown of 28 (50%) girls and 28 (50%) boys. The ethnic makeup includes white/Caucasian students (50%), followed by Hispanic students (25%) and African American students (15%), with the remainder coming from other ethnicities. Table 1 includes detailed student demographics.
Case Study Design

As previously noted, this research uses a case study design. Gall, Gall and Borg (2007) define a case study “as (a) the in-depth study of (b) one or more instances of a phenomenon (c) in its real-life context that (d) reflects the perspective of the participants involved in the phenomenon” (p. 447). The intent of a case study is to more deeply understand a certain phenomenon (Merriam, 1998). A phenomenon is a “process, event, person, or other item of interest to the researcher” and a case is a “particular instance of the phenomenon” (Gall, Gall, & Borg, 2007, p. 447). In this study, the specific phenomenon under study is how and why children demonstrate curiosity during technology-integrated learning. The case is a sixth grade mathematics classroom in a suburban Texas Title I school. Specifically, this study is a single case design with three embedded units of analysis (Yin, 2009). The embedded units of analysis are the three areas of mathematical learning; 1) mathematical procedural knowledge, 2) mathematical conceptual knowledge, and 3) mathematical problem solving knowledge.

There are three purposes of a case study: description, explanation, and evaluation (Gall, Gall, & Borg, 2007). The descriptive case study aims to describe the phenomenon using a thick
description. A thick description is one that does not stop at describing the action, but also describes the intentions, meanings and contexts of the action (Glesne, 2006). The explanatory case study looks beyond explaining and towards identifying patterns that can be used to gain an understanding of the phenomenon more generally (Cohen & Court, 2003; Gall, Gall, & Borg, 2007). While this case study is descriptive, it has an eye toward explanatory purposes if appropriate.

Because this research is utilizing the case study design with intense qualitative data collection methods, a subset of the students are used as the study participants to observe and interview. Observational data and document review data might also come from other sixth grade students for the purposes of triangulation. Specifically, thirteen students have been purposefully selected for the study. Wengraf (2006) noted that participant selection should be purposeful using criteria such as access to participants, their probability of speaking honestly, and their “capacity to express [their] experience in words” (p. 95). This sample was chosen to maintain a broad range of mathematical abilities and to maintain similar demographics to the sixth grade in general. Table 2 displays the demographics of all sixth grade students along with the demographics of the selected participants. Table 3 displays the academic progress of all sixth grade students along with the academic progress of the selected participants. As a measure of academic progress, the Response to Intervention Tier system was used (Fuchs & Fuchs, 2006). Specifically, Tier 1 students do not require mathematical intervention but instead should receive enrichment. Tier 2 and 3 students require mathematical intervention at different levels, specifically related to the size of the intervention group and the amount of time each week necessary in that group. Additionally, Wengraf’s (2006) consideration of access to participants manifested itself in students’ attendance at school so absences were evaluated. Finally, as
Wengraf (2006) recommends, the students were selected who have demonstrated a high ability to be metacognitive as this study requires students to reflect and think deeply about their own thinking and learning.

Following are descriptions of each participant with pseudonyms. In each description, a photograph and discussion of students’ math manifesto are included. At the beginning of the school year, students are asked to consider their mathematical hopes and dreams for the year. They then create a drawing of these goals which is placed in the classroom as their math manifesto.

Table 2

Demographic Comparison of All Sixth Grade Students and Case Study Participants

<table>
<thead>
<tr>
<th></th>
<th>% of Population</th>
<th>% of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economically Disadvantaged</td>
<td>52%</td>
<td>46%</td>
</tr>
<tr>
<td>Asian</td>
<td>9%</td>
<td>15%</td>
</tr>
<tr>
<td>Black</td>
<td>14%</td>
<td>15%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>White</td>
<td>50%</td>
<td>62%</td>
</tr>
<tr>
<td>Female</td>
<td>50%</td>
<td>54%</td>
</tr>
<tr>
<td>Male</td>
<td>50%</td>
<td>38%</td>
</tr>
<tr>
<td>Limited English Proficient</td>
<td>9%</td>
<td>0%</td>
</tr>
<tr>
<td>Special Education</td>
<td>11%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Table 3

Academic Progress Comparison of All Sixth Grade Students and Study Participants

<table>
<thead>
<tr>
<th></th>
<th>% of Population</th>
<th>% of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1</td>
<td>70%</td>
<td>69%</td>
</tr>
<tr>
<td>Tier 2</td>
<td>21%</td>
<td>23%</td>
</tr>
<tr>
<td>Tier 3</td>
<td>9%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Elizabeth is a White, female student. She is the only sixth grade student identified as a gifted student who was not placed in the Pre-Advanced Placement mathematics block. District personnel made all decisions regarding Pre-Advanced Placement selection. As shown in Figure 3, Elizabeth’s math manifesto states that her goal in math “is to start to enjoy math more, unlike the years before when I hated it.” Clearly, while she is a gifted thinker, she had not found relevance and purpose previously in her math classes. She did however perform well in mathematics. She scored an 84% on her fifth grade mathematics TAKS test. She is considered a Tier 1 student, indicating that she does not need mathematics intervention (Fuchs & Fuchs, 2006). Elizabeth is a slow worker, typically the last one to complete an assignment in class. However, she sets high standards for herself and works hard to succeed academically. When she is not doing school work, you would find Elizabeth enjoying herself by talking with her friends or reading.

Marissa is an African-American female who is considered economically disadvantaged. As shown in Figure 4, Marissa’s math manifesto states that her “goal in math is to get good grades on test (sic) and TAKS test or any quizzes (sic)”. Marissa has a heightened awareness of
the TAKS test as she did not pass her fifth grade TAKS test on the first or second administration. She earned a 50% on the first administration, a 57% on the second administration and a passing score of 70% on the third administration. Marissa is considered a Tier 3 student, indicating that she needs the highest level of mathematics intervention (Fuchs & Fuchs, 2006). During intervention, students are ability grouped with the Tier 3 students in very small groups. Concepts are re-taught during this time. As such, she receives math intervention for 45 minutes three times per week in addition to her mathematics block. Many students who struggle in one subject also struggle in other subjects. However, Marissa is identified as a Tier 1 student in reading and earned a commended score of 93% on the reading TAKS test in fifth grade. In math class, Marissa is a hard worker who wants to learn. She works more slowly than other students and typically likes to try many avenues to solve a problem before asking for help. Outside of math class, Marissa sings in the school choir and has performed as a singer at many school talent shows. She is a social child who enjoys visiting with her friends.

Matthew is an economically disadvantaged, White male. He has been identified as a gifted student and was also selected by the district for the Pre-Advanced Placement mathematics
Figure 5. Matthew’s math manifesto.

block. As shown in Figure 5, Matthew’s math manifesto, his “goal in math is to do my very best and try to get straight A’s.” Matthew is considered a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics and reading, earning a 93% on his fifth grade mathematics TAKS test. Matthew participates in the weekend food program at the school where non-perishable foods are given to students to take home for the weekend when there is concern that he or she might not otherwise have food. Matthew has a sleep disorder and can fall asleep at any time. Math class is active enough that he does not fall asleep, but struggles during silent reading to stay awake. He is a quiet child whose glasses typically sit half way down his nose. During math class, Matthew works hard to understand the concepts and is uncomfortable if he believes he does not understand. Sometimes, he will ask the teacher for help with a concept, but actually he understands it quite well. Most of the time, he can and does complete his work without assistance. Outside of math class, Matthew is usually playing basketball with a group of boys on the blacktop.

Karen is a White female who is identified as economically disadvantaged. She also has been identified as a special education student with a learning disability. Further, she accesses the
Karen’s math manifesto.

dyslexia therapy program through the district as well as dyslexia programs outside of school. As shown in Figure 6, Katilin’s math manifesto states that her goal is to “study more” which is interesting because between school and her dyslexia programs on weekends and summer breaks, she likely studies more than any of her peers. Karen is identified as a Tier 2 student (Fuchs & Fuchs, 2006) in mathematics, mostly because of her multitude of potential learning issues. She earned an 82% on her fifth grade mathematics TAKS test, a score that would have placed her as a Tier 1 student if she did not have the special education and/or dyslexia identification. Additionally, she has been identified as a student who is at risk of not graduating. Karen talks with a slight mumble and also has allergic reactions to egg products which keeps her face broken out most of the time. She is a happy child who is always smiling and offering her teachers hugs. Karen is aware of her struggles with learning and is self conscious about it, but works hard to overcome her difficulties.

Becky is an African American female who is identified as economically disadvantaged. As shown in Figure 7, Becky’s math manifesto states that her goal “is to get a better grip on everything on (sic) math and get an A+ on all of my math on every report card.” Her concern
about her “grip on everything” is well founded as she barely passed the fifth grade mathematics TAKS test with a score of 66%. Becky is identified as a Tier 2 student (Fuchs & Fuchs, 2006) for mathematics and receives small group mathematics intervention for 45 minutes three times per week in addition to her mathematics block. Becky is a very social child and while she obviously perceives that she needs a “better grip” on her mathematics knowledge, she is frequently seen around the classroom helping other students. Outside of math class, Becky flits from group to group and can be seen chatting with friends, playing volleyball or watching the soccer game. She talks constantly, leaving others wondering if she actually needs to breathe!

Figure 8. Kevin’s math manifesto.
Kevin is a White male. As shown in Figure 8, his math manifesto states that his goal in math is to pass 6th grade. Indeed, the district has identified Kevin as a student that is at risk of not graduating. Further, he scored a 59% on the first administration of the fifth grade mathematics TAKS test. He then passed the second administration, earning a score of 75%. Kevin has been identified as a Tier 2 student (Fuchs & Fuchs, 2006) for mathematics and receives small group mathematics intervention for 45 minutes three times per week in addition to his mathematics block. Kevin tends to lose everything and is very unorganized. His binder was completely destroyed by the end of the first month of school. If Kevin has homework, the teachers have learned that the best plan of action is to ask Kevin to stay after school to complete the work. Kevin will comply with that request because he understands his limitations with taking home work, completing it and bringing it back to the teacher. Early in the school year, Kevin lost his glasses. It took approximately six months to get replacement glasses even though he really struggles to see anything without them. During recess, Kevin is always playing soccer with a large group of children. He tends to play goalie as his large presence is seen as an intimidating factor for the opposing team.

Figure 9. Olivia’s math manifesto.
Olivia is a Hispanic female. She has been identified as economically disadvantaged. In her math manifesto shown in Figure 9, Olivia states that her “goal is to get A honor roll all year.” This goal indicates that Olivia understands the basic mathematical concepts and is ready to push herself to excel in mathematics. She earned an 82% on her fifth grade mathematics TAKS test, placing her as a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics. During math class, Olivia is usually one of the first children to be seated and begin working on the daily warm up exercise. While she is social, she does not allow her social life to interfere with her learning. Olivia is good friends with Marissa and can be seen with her daily during recess.

![Image](image.png)

**Figure 10.** Madison’s math manifesto.

Madison is an Asian female. She currently lives with her mother, step-father and step-brother and sister. She sees her father periodically as he lives in another city. In her math manifesto as shown in Figure 10, Madison states that her “goal is to use math in my studys (sic) and job as a vet.” This goal indicates that Madison is ready to find purpose in mathematics outside the classroom and has even begun to link her success in mathematics with her dream to become a veterinarian. Madison has been identified by the district as a gifted student and has been selected for the Pre-Advanced Placement mathematics block. She earned a commended score of 98% on the fifth grade mathematics TAKS test, placing her as a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics. Madison is an excellent student and an avid reader. She can be
seen walking down the hall with a book in her hand. When she goes to her physical education class, many times the coach has to send her back to class to leave her book so that it will not distract her! Sometimes she is seen chatting with her friends at recess or she plays imaginative games of Bakugan™ or Pokemon™ with a group of boys.

![Thomas's math manifesto](image)

*Figure 11. Thomas’s math manifesto.*

Thomas is a White male. He has been identified by the district as a gifted student and has been selected for the Pre-Advanced Placement mathematics block. On his math manifesto shown in Figure 11, Thomas states his “goal this year is to have fun in math.” This goal indicates Thomas’s confidence in his mathematical abilities and his desire to explore math more deeply. Thomas is covered under federal protections for students with disabilities as Thomas has Attention Deficit Hyperactivity Disorder, borderline Autism and extreme anxiety. Thomas scored a 100% on the fifth grade mathematics TAKS test, placing him as a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics. Thomas’s lack of social cues, coupled with his impulsivity, becomes apparent at times as he wants to share something important to him at inopportune times. He does not know how to wait to tell his story and will continue even when he is asked to wait. He typically plays imaginative games of Bakugan™ or Pokemon™ and sometimes recruits Madison to play the games with him. He also typically brings a small toy such as a Beyblade™ to school in his pocket so that he has something to do with his hands at all times. He also
typically has at least one bald spot on his head where his anxiety has compelled him to pull on his hair. His parents keep his hair cut very short because it reduces his desire and ability to pull his hair out and it also makes his bald spots less visible.

Figure 12. John’s math manifesto.

John is an Asian male. On his math manifesto shown in Figure 12, John stated his “goal is to stop making stupid mistakes.” John is a perfectionist and has high expectations for himself. He earned a commended score of 98% on his fifth grade mathematics TAKS test, but was convinced he missed a perfect score because of a “stupid mistake.” Like Thomas, John has been identified by the district as a gifted student and has been selected for the Pre-Advanced Placement mathematics block. John is a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics.

John has a wonderful sense of humor and does not mind laughing even at himself, which is typically difficult in adolescence! He is very intelligent but also humble. He does not see himself as too smart to document his work or his thinking. He is a voracious learner, looking for every opportunity to learn from every experience, text or activity. He is also an avid technology user who consistently pushes technology to its limits to see what it can do.
Allison is a Hispanic female. On her math manifesto shown in Figure 13, Allison stated her “goal in math is … how to use it in my life everyday and solve problems and equations much faster.” Like Madison, Allison is seeking a connection between her mathematical learning and her world outside the classroom. She also wants to develop more fluency in her mathematical processing. Allison has been selected by the district for the Pre-Advanced Placement mathematics block, however, she is not identified as a gifted student. Allison earned an 89% on the fifth grade mathematics TAKS test, missing the commended range by one question. She is a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics. Allison is an only child but her close relationship and almost constant companionship of her young cousin means that she does not suffer from the self-centeredness of many only children. She is a small but athletic child and typically plays volleyball with a group of friends during recess.

Jacob is a White male. In his math manifesto shown in Figure 14, Jacob stated his “goal is to get commended on the test in math.” He is referring to the mathematics TAKS test in which students earning 90% or higher are commended. In fifth grade, Jacob earned an 84% on his mathematics TAKS test, placing him as a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics.
However, Jacob has been identified by the district as at risk of not graduating. His father was paroled from prison this past summer and his older brother has a history of not meeting standard on TAKS tests. Jacob also suffers from attendance problems. He can be found on school nights with his family at hockey games and eating at restaurants very late at night and if this happens, his parents allow him to sleep the next day instead of going to school. His favorite activity is hockey which he plays every weekend. He likes playing forward but sometimes the team asks him to play goalie as well.
Sarah is a White female. She has been identified as an economically disadvantaged student. On her math manifesto shown in Figure 15, Sarah stated her “goal this year is to get straight A’s in math.” The district placed Sarah in the Pre-Advanced Placement mathematics block, however, she has not been identified as gifted. Sarah earned a commended score of 98% on the fifth grade mathematics TAKS test, placing her as a Tier 1 student (Fuchs & Fuchs, 2006) for mathematics. Sarah has a quick smile and is almost always in a pleasant mood. She works hard in class as she sets high standards for herself. She becomes frustrated with herself when she answers problems incorrectly. Outside of class, she enjoys talking with her friends. She also enjoys rollerblading and can be found around the neighborhood with her rollerblades on almost every day.

Table 4

**Participant Demographic Data**

<table>
<thead>
<tr>
<th>Demographic Data by Participant</th>
<th>Economically Disadvantaged</th>
<th>Asian</th>
<th>Black</th>
<th>Hispanic</th>
<th>White</th>
<th>Female</th>
<th>Male</th>
<th>Special Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elizabeth</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Marissa</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Matthew</td>
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<td>X</td>
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<tr>
<td>Karen</td>
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<tr>
<td>Becky</td>
<td>X</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td>Kevin</td>
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<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Olivia</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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<td></td>
<td>X</td>
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<tr>
<td>Madison</td>
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<td>X</td>
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<tr>
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<td>X</td>
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<tr>
<td>John</td>
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<td>X</td>
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<tr>
<td>Allison</td>
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<tr>
<td>Jacob</td>
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<td></td>
</tr>
<tr>
<td>Sarah</td>
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<td>X</td>
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<td>X</td>
</tr>
</tbody>
</table>

As a summary of the participants and their demographic profile is included in Table 4 below. Also, Table 5 shows a summary of the participants and their mathematics achievement
profile. These tables are offered so the reader can identify which student fit into particular demographic and achievement groups.

**Participant Role of the Researcher**

The researcher’s role in the study is that of a participant observer. As a participant, I am the teacher in the sixth grade mathematics classroom. As an observer, I am also the researcher studying the children’s curiosity when they interact with technology during their mathematics class. Fine and Glassner (1979) have identified four roles for researchers studying children: Leader, Friend, Supervisor and Observer (See Figure 16). The roles are classified based on the Table 5

**Participant Achievement Data**

<table>
<thead>
<tr>
<th>Achievement Data by Participant</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elizabeth</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marissa</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Matthew</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karen</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Becky</td>
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<td></td>
<td>X</td>
</tr>
<tr>
<td>Kevin</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Olivia</td>
<td>X</td>
<td></td>
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<tr>
<td>Madison</td>
<td></td>
<td>X</td>
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<tr>
<td>Thomas</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>John</td>
<td>X</td>
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<tr>
<td>Allison</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jacob</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sarah</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
contact and authority the adult has with the child. Both leader and friend are appropriate for participant observers. Indeed, teachers are among several professions, which fall into the Leader category because both positive contact and direct authority are present.

<table>
<thead>
<tr>
<th>Positive Contact</th>
<th>Direct Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
</tr>
<tr>
<td><strong>Present</strong></td>
<td>Leader</td>
</tr>
<tr>
<td><strong>Absent</strong></td>
<td>Supervisor</td>
</tr>
</tbody>
</table>

*Figure 16. Possible roles of adult researchers in observational settings with children.*

More recently, Denzin and Lincoln (2007) have addressed the roles of the observer and the observed, specifically noting:

Poststructuralists and postmodernists have contributed to the understanding that there is no clear window into the inner life of an individual. Any gaze is always filtered through the lenses of language, gender, social class, race and ethnicity. There are no objective observations, only observations socially situated in the worlds of – and between – the observer and the observed. Subjects, or individuals, are seldom able to give full explanations of their actions or intentions; all they can offer are accounts, or stories, about what they have done and why. No single method can grasp all the subtle variations in ongoing human experience. (p. 29).

Because individuals can only give partial explanations and because observations are always filtered, a participant observer is an ideal situation for this study. It is through dialogue and collaboration with the observer, the observed and “outsiders” that data are evaluated.

I am not the first researcher to study children in her own classroom. In fact, Lampert (2000) and others (e.g., see Bass, 1999) pushes research methods farther by studying herself as
she teaches. While that is not my role as I am studying children rather than myself, Lampert certainly offers support for teachers as researchers in their own classrooms. Further, Anderson and Herr (1999) offer several specific validity checks for researchers studying themselves or their classroom. For example, outcome validity is whether resolution occurs to the problem under study so that problems are then reframed in a more complex manner allowing for long term study. This particular validity check is not appropriate for this study as it is designed to have time constraints. A unique validity check that is applicable to this study and is recommended is dialogic validity in which validity is strengthened via dialogue with a critical friend who is familiar with the context and can play the role of Devil’s Advocate for alternative explanations of research data. My colleague serves that role for this research. This colleague earned her doctoral degree in 2004 with a qualitative dissertation. She is a 24 year veteran classroom teacher who works in the same district. In addition, validity checks such as triangulation or the use of multiple methods of gathering data (Glesne, 2006) are suggested for all qualitative research. The study design of a case study with the researcher as a participant observer is not uncommon (e.g., see Dondlinger, 2009; Vasinda, 2004) and can be accomplished with rigor.

While the researcher was a participant in the classroom, the role of the researcher or the teacher was not the purpose of the study. Thus, the findings do not address any aspect of the teacher’s actions during the study. The teacher was fully present during the entire study. I provided scaffolding for students who were struggling with the work and encouragement for students who needed it. I answered questions and provided troubleshooting assistance as required. During the learning, I offered a brief overview of what students were to accomplish. I then made my way around the room addressing any questions or offering assistance as needed.
However, recall that the purpose of the study is to examine students’ curiosity, not teacher actions. Thus, the findings of this study only include the students’ thoughts, work and utterances.

Data Collection

Data collection includes qualitative techniques such as teacher observations, student interviews, and student written reflections they keep in weblogs (blogs). Textual data is analyzed according to Gall, Gall & Borg (2007) suggested methods for document analysis and takes place during the fourth six weeks of the 2010 – 2011 school year. Each week of the six weeks focuses on a different technology-integrated learning experience.

Student interviews are the major source of data and occurred weekly during the study. Students from each of the three math class periods, also known as blocks, were interviewed each week. The interviews were semi-structured, with the interview protocol included as an Appendix A. These interviews were recorded and transcribed for analysis. Triangulation occurred with teacher observation, student weblog reflections and document analysis. Teacher observation included two methods. First, the teacher researcher made observations of students and documented these observations daily in a journal. Additionally, the district middle school mathematics instructional specialist and the assistant principal videotaped the students during the technology-integrated learning experience. Then, both the instructional specialist and the teacher researcher reviewed and coded the videotape. Other data collection included student reflections in weblogs that were used regularly in class and document analysis of student work and other learning artifacts.

The context of the study included computer use as needed within the mathematics classroom. Technology was plentiful enough that students could use a laptop each day during
math without sharing, centers or taking turns. Laptop computers were used with one class set being available in the mathematics classroom. Students rotate through the mathematics classroom for approximately eighty-minute blocks each day. Students were engaged in a variety of work products including drill and practice, virtual manipulatives, Internet searching, electronic mail, programming and creating Web 2.0 products such as blogs and podcasts.

The technology-integrated work that was the subject of the study fell into three categories:

1) Using technology for procedural knowledge
2) Using technology to deepen conceptual knowledge
3) Using technology with problem solving

For all technology-integrated work, data collected included teacher observations, student interviews and student reactions in weblogs.

Using Technology for Procedural Knowledge

Mathematics is a procedural study that relies on algorithms to consistently arrive at correct answers (Papert, 1983), thus it makes sense to use at least one example of technology-integrated learning for procedural knowledge. In this case, students’ use of Study Buddies™, a product from Brainchild, was examined. It is a handheld device similar to a Nintendo DS™ or Leapfrog Leapster™ with cartridges for content. Figure 17 shows a Study Buddy™ device.

The Study Buddies™ cartridges are directly aligned to the Texas Essential Knowledge and Skills (TEKS) and are considered computer-aided instruction (Roblyer & Doering, 2010). Each standard offers a brief multimedia lesson along with questions that can be answered in
practice mode or test mode. If students are in practice mode, they are afforded immediate feedback along with guidance if they answer incorrectly. These devices were checked out to students on a rotational basis each week for homework. Students practice at home and then, in-class, use the Study Buddy™ in test mode for their homework grade. These devices were acquired with grant funds from the Foundation for Allen Schools specifically to target and improve students’ procedural knowledge while making their mathematical practice productive.

Using Technology to Deepen Conceptual Knowledge

While mathematics is a procedural study, understanding the underlying concepts is important for students to be able to apply learning to new situations. Indeed, even if the procedural knowledge is lacking, strong conceptual knowledge can help students navigate challenging mathematical problems. Conceptual knowledge work included deepening students’ concepts of ratio, proportion, percents, and decimal and fractional equivalents to percents. Conceptual knowledge building websites such as the National Library of Virtual Manipulatives (Bouck & Flanagan, 2010; Reimer & Moyer, 2005) assist students in building mental models of the mathematical concepts, or completing project work designed to deepen conceptual knowledge while using technology as tool.
Specifically for this study, students used a variety of websites to deepen their conceptual knowledge. Students were beginning a study of ratios and proportions, a new concept in sixth grade. After students understood the concept of ratio, we moved to a conceptual understand of proportion as two equivalent ratios. This work, displayed in Figure 18, is from the LearnAlberta.ca website’s Math Interactives. During their interaction, students connected proportions with photography and decide whether a targeted ratio or enlarged photograph was equivalent to the original ratio or original photograph. Important aspects of this work include the multiplier across the top of the workspace which connects the students to the mathematics necessary to decide whether ratios are proportional and the visual mathematical feedback that students receive when they clicked a multiplier as the outline of the photograph responded. During the interviews, this work was called resizing images.

![Figure 18. Screenshot of proportion conceptual knowledge work.](image)

Once students understood conceptually the definition of a proportion, the next work assisted students in building a model of using proportions to solve for an unknown. MathPlayground.com hosts the Thinking Blocks manipulative for this work and is shown in Figure 19 below. Students were presented with a problem and work to build a model of the ratio that they then label and use to solve the problem. Students must click the check button between each step for feedback. During the interviews, this work was called Thinking Blocks.
During the next week, students learned about percents as a ratio and also modeled percent, decimal and fractional equivalents. First, students needed a mental model of a percent since sixth grade is the first year that students are working with percents. As shown in Figure 20, students used the National Library of Virtual Manipulatives (NLVM) to build their conceptual knowledge of percents. Students began in show mode and were presented with a blank ten by ten grid. They were presented with a question that asked them to show a certain percent. They also obtained feedback about their answers. Students could also navigate to explore or show modes to learn in different ways. During the interviews, this work was called Percent Grid. This same grid with 100 squares was used throughout the week to continue to develop and reinforce students’ conceptual knowledge of a percent.

After students gained an understanding of a percent, they needed to incorporate this understanding into their existing knowledge of decimals and fractions. Earlier in the year, students had studied decimal and fractional equivalents and built mental models of those
concepts. As shown in Figure 21, students used the NLVM manipulative for representing decimals. This manipulative offered students random decimals that they modeled. Then, they sketched the model of the decimal along with the percent model using the hundreds grid. They also wrote the decimal and the percent. This work was called Decimal to percent during the interviews.

Finally, students incorporated their models of fractions into their new percent knowledge using a virtual manipulative on Shodor.org and shown in Figure 22. Students were presented
with a fraction. They then use the next blank box to create their percent grid by making 10 rows and 10 columns. As they shade their percent model, the arrow on the number line moved to offer mathematical feedback as to the size of the model they created. Once students had an equivalency match between the fraction and the percent models, they documented their work by sketching their results on paper. This work was called Fractions to percents during the interviews.

Certainly, students’ competency beliefs influence curiosity (Kashdan & Fincham, 2004) and when students have the procedural knowledge and the conceptual knowledge, they will be more likely to view themselves as competent.

![Image of fraction and percent model]

**Figure 22.** Screenshot of students work to build fraction and percent equivalents.

*Using Technology with Problem Solving*

Problem solving is the application of mathematical thinking in complex or novel situations. Problem solving work is essential for students because it assists them in transferring their new learning into different situations (Bransford, Brown & Cocking, 2000). Problem
solving can be open-ended, complex and meaningful work, which has been shown to invoke curiosity (Berlyne, 1954; Corlis & Weiss, 1973; Kashdan, 2004; Loewenstein, 1994). There are three types of technology-integrated problem solving work: 1) Mathcasts (Fahlberg, Fahlberg-Stojanovska & MacNeil, 2006; Fahlberg-Stojanovska, Fahlberg & King, 2008) for solving problems; 2) Math Out Loud for working with vocabulary; and 3) Folders of Wisdom and Knowledge for organization of mathematical knowledge.

Mathcasts (Fahlberg, Fahlberg-Stojanovska & MacNeil, 2006; Fahlberg-Stojanovska, Fahlberg & King, 2008) is a term used to describe digitally captured voice and writing that document students’ thinking while they solve math problems. The name is derived from a combination of the words mathematics and screencasting. The mathcasts can then be replayed so that students and others can hear students’ thinking. These mathcasts use digital pens, are uploaded online and are used to help students self-assess their mathematical thinking and gain exposure to others’ thinking (Vasinda & McLeod, in press a). Brookhart, Andolina, Zuza and Furman (2004) found in a study of third graders that self-assessment was successful in moving a rote memorization task such as learning multiplications facts into deeper learning where students became aware of and monitored their own mathematical learning. When students increase their knowledge or increase their awareness of the gaps in their knowledge, curiosity will be sparked (Berlyne & Frommer, 1966; Kashdan, 2004; Loewenstein, 1994). Mathcasts also allow students to listen to themselves and one another, which can spark their awareness of any gaps in their knowledge. Students were partnered to record their mathcasts. One student was the interviewer and the other student was the problem solver. The interviewer used a protocol to scaffold students through their think aloud of their problem solving. They were also able to assist the problem solver if necessary. Then, students switched roles and solved another problem.
Mathcasts were then uploaded to the class learning management system. Students listened to each other and responded to each others’ mathcast with the prompt, “I saw your strong mathematical thinking when…”. Students also listened to themselves and could respond noting their own strong mathematical thinking or could respond noting what they could have differently to solve the problem. A few of the mathcasts were then uploaded to a public website which is depicted in Figure 23 below.

Math Out Loud is a way for students to immerse themselves in mathematical vocabulary. Particularly for English as a Second Language students, academic vocabulary can be challenging and a stumbling block to learning. Math Out Loud is a student-created and podcasted word story using a mathematical vocabulary word. The story is researched and written in small groups. There are five required elements to the word story: 1) a hook to encourage the audience to listen to the word story; 2) a definition of the word; 3) the etymology of the word; 4) examples of the word; and 5) non-examples of the word. The group then podcasts the story for publication online as shown in Figure 24. When students’ work is published online, they set high standards for the quality of their work (McLeod & Vasinda, 2008b; Vasinda & McLeod, in press b). Math Out

Figure 23. Screenshot of students’ public mathcast portal.
Loud also provides students a sense of relationship with others as the podcasts are posted online and some amount of autonomy or choice in the work as the word stories are created by the students with only story structure scaffolds. Both of these aspects are factors that invoke curiosity (Kashdan & Fincham, 2004).

One of the main differences in the way experts think about problems and the way novices think about problems is the organization of their knowledge (Bransford, Brown & Cocking, 2000). Organization of knowledge can be particularly challenging for mathematics learning because it is typically taught in small bits with little overarching structure to allow novices to understand the big picture (Papert, 1983). The Folders of Wisdom and Knowledge were created by the researcher to help students with their organization of their mathematical knowledge. As a part of this work, students sort questions or scenarios into categories to help them understand how concepts fit together and when certain knowledge can be applied. The sorting became a digital process to allow students the opportunity to think individually with immediate feedback (for further discussion of this process, see McLeod, Lin & Vasinda, in press). The digital

![Figure 24. Screenshot of students’ online Math Out Loud podcasted word story work.](image-url)
process, called virtual sorting, uses a Microsoft Excel spreadsheet with simple programming to allow students to select their mathematical concept from a dropdown list. The spreadsheet was also programmed to offer feedback to students. Figure 25 depicts a screenshot of the spreadsheet.

As previously noted, all data collection processes were the same for the different types of technology-integrated learning examined. One of these learning experiences happened each week and data were collected on that learning experience. Specifically, students were observed by the teacher and videotaped by the district mathematics instructional specialist, students were also interviewed, and students additionally responded and reacted via reflections in weblogs.

Figure 25. Screenshot of the virtual sorting spreadsheet.

Data Analysis

The data analysis used a qualitative, constant-comparative approach to allow themes to emerge (Gall, Gall & Borg, 2007; Strauss & Corbin, 1998). The constant-comparative approach is appropriate as it seeks to answer questions about the meaning of social experiences (Denzin & Lincoln, 2003). By using constant-comparative, researchers can clarify and make distinctions
between categories and also determine which categories are important to continue to study (Gall, Gall & Brog, 2007).

Data analysis of the study began by transcribing the video, interviews, and weblog reflections. First, codes were developed from the data which were constantly compared to other codes and to new data. Codes were also grouped with other common codes to find categories and categories were merged into themes. This is considered the open coding phase (Strauss & Corbin, 1998). During the next coding phase, axial, researchers take another pass through the data to ensure that the codes and categories capture the essence of the data (Strauss & Corbin, 1998). In the final phase, the selective phase, researchers find illustrative examples for the themes (Strauss & Corbin, 1998).

Validity checks of the data included triangulation using the different sources of data and dialogic validity of the critical friend. For the triangulation, all data sources were evaluated, including the interviews, the video observations, the weblog reflections and document analysis. Codes, categories and themes were analyzed to ensure that assertions could be supported by data from different sources. Further, validity procedures included the analysis of the data by a critical friend who completed her ethnographic dissertation in 2004 and a non-school district affiliated researcher who completed her case study dissertation in 2009. These two individuals ensured that the researcher was not overstating or inferring too much from the data.

Summary

Curiosity is crucial to students as they grow to become lifelong learners. It is not reserved for the elite or the gifted but is a capacity of all people. Technology and computer use is a significant part of our world and can be another tool for learning. But the ways in which technology is leveraged is key and determines whether or not students’ capacity for curiosity is
used or not. Using qualitative methods, this study examined the ways students demonstrate their curiosity in a sixth grade technology-rich mathematics classroom. This study has significant impact for educators as society looks to schools to ready students for twenty-first century skills and learning.
CHAPTER 4

FINDINGS

This chapter presents the results of the data analysis. It includes discussions of the codes, the categories and the themes identified during data analysis. It further defines the procedures used to determine the importance of each code in answering the research questions. To improve readability and so that the might be able to easily differentiate between the labels for codes, categories, and themes, *codes* are italicized, *categories* are bolded, and *themes* are bolded and italicized. The research questions for this study are as follows:

1. Do sixth grade students demonstrate curiosity in the mathematics classroom with technology-integrated learning? And if so,

2. How and why do sixth grade students demonstrate curiosity when learning mathematical procedural knowledge using technology?

3. How and why do sixth grade students demonstrate curiosity when learning mathematical conceptual knowledge using technology?

4. How and why do sixth grade students demonstrate curiosity when learning mathematical problem solving using technology?

Analysis Procedures

After the interviews were transcribed, the researchers coded each line of data while constantly evaluating the codes, adding new codes and refining existing ones. Recall that all questions were asking specifically about curiosity behaviors without asking the students about whether they were curious. The semi-structured interview protocol is included in Appendix A. The researchers were careful to examine the question to which the students were responding. For
example, if the interview question was “Describe a time when you were actively exploring for as much information as you could,” the researchers did not code those responses with a code of exploration as it would not yield usable results. There would be large sections of text coded as exploration when the students were actually answering a specific question about exploration. As another example, one of the interview questions was “Describe a time when the work was complex or challenging.” The responses to this interview question were not coded with the challenge code. Instead, in situations such as these, the student responses were evaluated for the underlying reason for the exploration or for the reason the students persisted even though they were challenged. The researchers believed that coding in this way would better address the research questions, particularly the “why” question, because it looked for students’ claims of the underlying reason for their actions or thoughts. Further, the researchers sought to identify the underlying reasons for students’ curiosity in general. No code of curiosity exists, nor does a curiosity category or theme exist. This was intentional as the researchers sought to answer the “how” and “why” questions. By doing so, it became apparent that curiosity was present in the classroom, addressing the first research question about whether students were curious. But, it also offered the substantive reasons that students were curious, which is more useful to educators than just the knowledge of curiosity’s presence.

As the interviews were coded, new codes emerged. Therefore, when all interviews had been initially coded and all codes defined, the researchers reviewed all the transcripts again looking for lines that were not properly coded based on the way the code had finally been defined. The researchers also looked for lines that were not coded because a code had emerged after that interview had been initially coded.
After approximately half of the interviews had been initially coded, the researchers began to look at the codes for emerging categories. The researchers initially identified five categories that were later merged into the four categories that were in place at the end of coding. As new codes were added during the coding, those codes were also evaluated within the context of the categories, looking for how the code fit within existing categories or whether there was need for a new category. When coding was complete, there were 60 codes that fit into the following four categories: 1) **self-regulatory behaviors**; 2) **discovery and learning**; 3) **digital tools**; and 4) **emotional connections to learning**. A code reference document is included in Appendix B. It is an alphabetical list of every code identified during the study, the definition of the code and an illuminating example using students’ words from the interviews.

**Findings from Research Questions**

The remainder of this chapter describes the findings for each research question and also evaluates the findings across the categories. The first research question asks whether students demonstrate curiosity in a technology-rich sixth grade mathematics classroom. Recall that the interview protocol (included in Appendix A) is not so transparent as to specifically ask if the students are curious. Instead, it asked students to describe times when they engaged in the research derived characteristics of curiosity such as exploration and persistence. However, by responding consistently week after week to those questions, students indirectly acknowledged their curiosity. Some students during some weeks indicated that they did not experience a particular characteristic of curiosity. For example, a student might have responded that he or she did not really explore much that week. However, those answers were not consistent during any particular week or for any particular student. Thus, the first research question can be answered in
the affirmative. Students do demonstrate curiosity in a technology-rich sixth grade mathematics classroom.

The remainder of the research questions have been listed and addressed in the same order since the beginning of this document. However in this section, the findings will shift the procedural knowledge to the end and instead begin with conceptual knowledge as it improves the communication of the findings. The findings from the research questions are addressed by examining the codes within each category and also communicated graphically using Figure 26.

![Graphical representation of findings from research questions.](image)

*Figure 26. Graphical representation of findings from research questions.*

The categories that emerged from the data included: 1) **self-regulatory behaviors**; 2) **discovery and learning**; 3) **digital tools**; and 4) **emotional connections to learning**. While the interview questions addressed curiosity specifically, the research questions compelled a deeper analysis of the data in order to illuminate the underlying reasons for the curiosity. Thus, while none of the questions asked about **self-regulatory behaviors**, **discovery and learning**, **digital tools** or **emotional connections to learning**, these categories did emerge from the researchers’ coding as the researchers sought to identify the underlying reasons for students’ curiosity.
Table 6

*Codes Organized into the Self-regulatory Behaviors Category*

<table>
<thead>
<tr>
<th>Self-regulatory behaviors codes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiating Behaviors (setting goals)</td>
<td>Flow</td>
</tr>
<tr>
<td>Maintaining Focus/Engaged</td>
<td>Intrinsic reward</td>
</tr>
<tr>
<td>Managing Time</td>
<td>Persistence</td>
</tr>
<tr>
<td>Accepting ownership</td>
<td>Lack of Purpose/Organization</td>
</tr>
<tr>
<td>Self-evaluation</td>
<td>Denying Ownership (Something Wrong w/ my Computer)</td>
</tr>
<tr>
<td>Leveraging Resources (Knowing Self as Learner/ Seeking Help)</td>
<td></td>
</tr>
</tbody>
</table>

**Self-regulatory behaviors** include the ability to monitor and control one’s own behavior, thinking, and emotions as one acquires knowledge and skills during learning (Zimmerman & Schunk, 2001). It involves the ability to actively control our behavior through access to resources (time, study environment, peers, and teachers), our motivational beliefs (self-efficacy and affect such as anxiety), and cognitive strategies for learning (self-talk, self-understanding, learning preferences). Table 6 displays the 11 codes that were organized into the **self-regulatory behaviors** category. Note that this code is not learning in and of itself, but it is the behaviors that make one a self-sufficient learner and increase the likelihood of learning success. Recall that all codes are specifically defined with examples of students’ words in the code reference document included as Appendix B. Not all codes were deemed important codes and this listing of all the codes in the category is meant to offer the reader information as to the breadth of the category. The relative importance of each code is addressed as the findings are delineated for each of the remaining research questions. These findings with the important codes identified and defined in detail offer the reader the depth of the category and code in that particular situation.

**Discovery and learning** includes students discussing the state, process or evolution of their learning. It also includes the manner in which students communicate mathematically. Table
Table 7

**Codes Organized into the Discovery and Learning Category**

<table>
<thead>
<tr>
<th>Discovery and learning codes</th>
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<tbody>
<tr>
<td>Seeking Information</td>
</tr>
<tr>
<td>Constructing Knowledge (at first)</td>
</tr>
<tr>
<td>Making Connections</td>
</tr>
<tr>
<td>Distinguishing Differences</td>
</tr>
<tr>
<td>Trial &amp; Error</td>
</tr>
<tr>
<td>Gap in Knowledge</td>
</tr>
<tr>
<td>Experiment</td>
</tr>
<tr>
<td>Aha!</td>
</tr>
<tr>
<td>Pulling Together Fragments</td>
</tr>
<tr>
<td>Thinking Past the Question/Remote</td>
</tr>
<tr>
<td>Transfer</td>
</tr>
<tr>
<td>Visual Modeling</td>
</tr>
<tr>
<td>Expressing math/Math talk</td>
</tr>
<tr>
<td>Social scaffold</td>
</tr>
<tr>
<td>Sketching math</td>
</tr>
<tr>
<td>Concept labels</td>
</tr>
<tr>
<td>Group dynamics</td>
</tr>
<tr>
<td>Invented play</td>
</tr>
<tr>
<td>Social construction of knowledge</td>
</tr>
<tr>
<td>Critical &amp; evaluative thinking</td>
</tr>
<tr>
<td>Inventive problem solving</td>
</tr>
</tbody>
</table>

7 displays the codes that were organized into the **discovery and learning** category. For example, this category includes student constructions of knowledge, how students experiment as they acquire knowledge, when students move beyond the required task and do more than they are asked to do, and when they express themselves mathematically. Recall that all codes are specifically defined with examples of students’ words in the code reference document included as Appendix B. Not all codes were deemed important codes and this listing of all the codes in the category is meant to offer the reader information as to the breadth of the category. The relative importance of each code is addressed as the findings are delineated for each of the remaining research questions. These findings with the important codes identified and defined in detail offer the reader the depth of the category and code in that particular situation.

The **digital tools** category includes students’ discussions of the technology used during their learning that week. Table 8 displays the codes that were organized into the **digital tools**
Table 8

*Codes Organized into the Digital Tools Category*

<table>
<thead>
<tr>
<th>Digital tools</th>
<th>Why/Impediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplification of Effort/Input</td>
<td>Technology Impediment</td>
</tr>
<tr>
<td>Material Intelligence</td>
<td>Technology vs. Math</td>
</tr>
<tr>
<td>Technology Scaffold</td>
<td>Disappointment with technology</td>
</tr>
<tr>
<td>Addicting</td>
<td>User inexperience</td>
</tr>
<tr>
<td>It’s Virtual</td>
<td>Fun vs learning</td>
</tr>
<tr>
<td>Wide Audience</td>
<td>Access to Technology</td>
</tr>
<tr>
<td>Going at own speed</td>
<td>Seeing possibilities</td>
</tr>
<tr>
<td>Pushing Tech to Its Limits</td>
<td>Novelty</td>
</tr>
</tbody>
</table>

category. It includes technology’s affordances, scaffolds, and impediments. Recall that all codes are specifically defined with examples of students’ words in the code reference document included as Appendix B. Not all codes were deemed important codes and this listing of all the codes in the category is meant to offer the reader information as to the breadth of the category. The relative importance of each code is addressed as the findings are delineated for each of the remaining research questions. These findings with the important codes identified and defined in detail offer the reader the depth of the category and code in that particular situation.

Table 9

*Codes Organized into the Emotional Connections to Learning Category*

<table>
<thead>
<tr>
<th>Emotional Connections to Learning</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge</td>
<td>Social responsibility</td>
</tr>
<tr>
<td>Easy</td>
<td>Compliance</td>
</tr>
<tr>
<td>Feelings of Competency</td>
<td>Confused</td>
</tr>
<tr>
<td>Freaking Out/Relieved</td>
<td>Feelings of Incompetency</td>
</tr>
<tr>
<td>Fun</td>
<td>Frustrated</td>
</tr>
<tr>
<td>Happy</td>
<td>Self conscious</td>
</tr>
<tr>
<td>Hard Fun</td>
<td></td>
</tr>
</tbody>
</table>
Finally, the emotional connections to learning include the emotions expressed by the students during the interviews. Table 9 displays the codes that were organized into this category. There were positive emotions such as fun and easy. There were also negative emotions such as frustration and confusion. The researchers also noted when students’ words were demonstrating feelings of competency or feelings of incompetency and those codes were included in this category. Recall that all codes are specifically defined with examples of students’ words in the code reference document included as Appendix B. Not all codes were deemed important codes and this listing of all the codes in the category is meant to offer the reader information as to the breadth of the category. The relative importance of each code is addressed as the findings are delineated for each of the remaining research questions. These findings with the important codes identified and defined in detail offer the reader the depth of the category and code in that particular situation.

As the categories are introduced, it becomes even more evident that curiosity was present during the course of the study. Recall that five connections were synthesized from the literature from curiosity to education. The five areas of particular interest to educators are: 1) curiosity’s connection to knowledge and higher order thinking; 2) curiosity’s connection to motivation and persistence; 3) curiosity’s connection with goal oriented behavior; 4) curiosity’s reciprocal nature; and 5) curiosity’s antitheses of boredom and anxiety. The categories identified during the study directly align to the first three areas of interest. Specifically, the first area of interest is curiosity’s connection to knowledge and higher order thinking. This connection is clearly demonstrated in the category of discovery and learning. In other words, when the students were asked to describe times when they were demonstrating the characteristics of curiosity and the researchers searched for the underlying constructs or the underlying reasons for the students’
curiosity, one of the categories that emerged, discovery and learning, aligned perfectly with the research on curiosity and its importance and relevance to educators. In the same manner, the category of self-regulatory behaviors aligns to the research connecting curiosity with persistence and goal oriented behavior. Further, the category of emotional connections to learning aligns with curiosity’s connection to motivation. The fourth important aspect of curiosity, its reciprocal nature, was not specifically examined or identified in the study. Finally, the fifth important aspect of curiosity to educators is its antitheses of boredom and anxiety. Those are negatively correlated and thus we would look for their absence as an indication of curiosity’s strength of presence. Indeed, boredom was completely absent from the study. Anxiety could be seen in some situations as students were struggling to learn challenging concepts or were setting high expectations for themselves because their work would be publicly posted on the Internet. However, these emotions did not seem to eclipse the presence of curiosity during the study.

The important codes for each category during each type of knowledge work are discussed in detail below. The researchers used the percentage of the data coded with each code within each category to determine which codes were most important for each research question. For example, when examining the research question for problem solving knowledge, the researchers extracted the data from three interviews that explored problem solving knowledge. They then viewed the percent of each interview that was coded with each code within each category. An average across the three weeks for each code was calculated and used to determine the relative importance of the code for that research question. Researchers then looked for a natural break between percentages as a cutoff for the important codes. In some situations, a code below the natural break was used if it offered a more balanced view of the data. For example, in the
emotional connections to learning category during the conceptual knowledge work, the code of confused was added to the important list so as not to convey the message that the entire week was full of positive feelings. Further, as the categories and codes are described, students’ words are used to illuminate the meaning of the code. In all cases, the quotes that are used are selected because they are particularly suited to describe the code. They were not selected based on gender of the student. Indeed, no attempt was made to analyze or evaluate gender differences in the data. After the research questions are addressed, findings are discussed across the categories. This process resulted in three specific themes from the data.

Findings from Learning Mathematical Conceptual Knowledge using Technology

Interviews from the first two weeks addressed the mathematical conceptual knowledge work. These interviews answer the third research question that asks how and why students demonstrate curiosity during mathematical conceptual knowledge using technology. Table 10 depicts the data that are graphically displayed in Figure 26 above. Specifically, it lists the percent of first two weeks’ interviews that were coded with each category.

Table 10
Percent of First Two Weeks’ Interviews Coded with each Category

<table>
<thead>
<tr>
<th>Category</th>
<th>Conceptual Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-regulation</td>
<td>14%</td>
</tr>
<tr>
<td>Discovery &amp; Learning</td>
<td>31%</td>
</tr>
<tr>
<td>Digital tools</td>
<td>28%</td>
</tr>
<tr>
<td>Emotional Connections</td>
<td>27%</td>
</tr>
</tbody>
</table>

Clearly, discovery and learning drew a significant amount of the discussion during these weeks, followed by the digital tools students were using to help construct that knowledge.
Indeed, all four categories were more tightly coupled during the conceptual knowledge work than with problem solving work or procedural work. This coupling may indicate that this type of work requires many types of knowledge and behavior acting in concert for the learner to be successful. However, a more detailed examination of the important codes in each category is necessary to draw any conclusions. Thus, each category is examined next, with the most important codes discussed and evaluated.

For the category of self-regulatory behaviors, two codes seemed to dominate the students’ discussions as displayed in Table 11 below. Specifically, the codes of persistence and leveraging resources were used most often during those interviews. Thus, of the self-regulatory behaviors found in these interviews, those two were cited most often by students as they completed their conceptual knowledge work.

Table 11

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 1</td>
<td>Week 2</td>
<td>Average</td>
</tr>
<tr>
<td>persistence</td>
<td>11.4%</td>
<td>5.9%</td>
<td>8.6%</td>
</tr>
<tr>
<td>leveraging resources</td>
<td>10.4%</td>
<td>5.2%</td>
<td></td>
</tr>
</tbody>
</table>

Persistence is when students continue to work even when confronted with challenge or frustration or when the allotted time has expired. This code was found in both weeks of conceptual knowledge building work. It was the highest used code in this category during Week 1 and the second highest used code in this category during Week 2. Persistence is also a characteristic of curiosity noted in the research (Kashdan, Steger, & Breen, 2007; Schmitt & Lahroodi, 2008). Students demonstrated persistence in a variety of ways. For example,
sometimes students noted that they persisted during a challenging situation. They also could have done an exceptional amount of work even through the challenge. During the Week 1 interview, Becky discussed her persistence while working on resizing images. She said, “The higher I went the faster I went and, because the higher I went the easier they became because at first they were harder and harder and then as soon as I hit like 70, they started getting easier and easier and I started going like, I was going boom, boom, boom.” In this piece of data, Becky notes that she did a substantial amount of work just by completing 70 of the resizing images problems. Indeed, I did not ask student to complete a particular number of problems during the resizing images work. Certainly, if I had assigned the work with a number of problems required, my requirement would have been less than 70. While working with resizing images, students created a game where they kept track of how many problems they worked using tallies, so she knew exactly how many she had accomplished. In fact, Becky completed more of these problems than any other child in sixth grade. She did this in spite of the fact that at first the problems were “harder and harder and harder” which truly demonstrates her persistence. Other students discussed their persistence without a reference to exactly how many problems they completed. For example, Sarah discussed her challenge with the Thinking Blocks manipulative and noted, “The thing that I thought was really difficult was in the Thinking Blocks and I thought it was just to think of all the things everywhere and I just didn’t like it because I was really confused and angry at the same time. What I did to help myself was that I just kept going with it. I didn’t just like quit.” Note that she did not specify exactly how many problems she worked, but she did specifically note her intention to persist by saying that she did not quit even though she was frustrated and confused. Another student noted her persistence with her meticulous attitude about the work. Specifically, Elizabeth discussed the way she approached the resizing images work and
noted that she “took my time on it and double checked everything even though I went really slow on one problem, I completely understood it when I was done.” While she did not accomplish a significant number of problems like Becky, she did demonstrate persistence in that she worked very hard on each one and felt that she “completely understood” the concept when she was finished.

Sometimes, students’ discussed their persistence without an accompanying physical action. In other words, while Becky, Sarah and Elizabeth worked problems to physically demonstrate their persistence, some students noted that they thought about problems for long periods of time or even after the work had concluded. These instances were also considered persistence. For example, Marissa discussed her work with resizing images and noted that she “was trying to get more information about the ratios and they gave us the key numbers but you had to find the rest of the things out and you have to really think about it.” Also, Madison noted this invisible persistence when she discussed her work with decimal and percent equivalents. She said, “I think the thing that made me explore more was the decimals to percents because it was fun… there was this one question where I got like 4.67 and I thought that ummm… would this be a real percent if it was originally created to be that. It made me want to think about that. Luckily it was my last question so I could sit there and think about it for a little bit.” This willingness to continue with the hard cognitive work of thinking demonstrated that the students did not even consider quitting but that they even willingly continued their work after the learning activities were completed.

The second self-regulatory behavior code that was used significantly during the conceptual knowledge work was leveraging resources. This code was used when students expressed some strategy that was used to help them in a difficult situation. They were
demonstrating that they could self-assess that they were in a challenging situation and that they
had tools they could use before they asked someone else for help, although asking for help is one
strategy that they might have deployed. Note that this code appears to be absent during the Week
2 interview. Actually, it was used during Week 2, but the percent of the interview that was coded
with *leveraging resources* was so small that it did not appear. However, it was used so much
during Week 1 though that it still remained a significant code for the average of both weeks.
Reflectively, it is not surprising that this code was almost absent from the Week 2 interview.
Overall, students considered the Week 2 work much easier than the Week 1 work. Thus, they
had less need to leverage any resources or use any strategies. During Week 1, John notes that he
leveraged resources with a strategy while working on the Thinking Blocks manipulative. He
said, “Well on that Thinking Blocks thing… I was confused by all these numbers and the
question mark thing… So what I did to help myself was that I slowed down and I started reading
these problem solving steps and I got a feel for it.” Also, Allison noted she needed several
different strategies to help her through the Thinking Blocks work. She said,

I think the Thinking Blocks were challenging… because I had to visualize it and I had to
write it down and hear it too. So I had to like do all this to understand it. So I had to get
that piece of paper again and write it down because it was making me mad because I
couldn’t do it without the paper. And I sort of read it as a whisper so that I could hear
myself. I have to hear it, visualize it and write it down too or I just don’t see it. So that
was making me mad. So I was reading it to myself and I was looking at it and I wrote it
down and it was less complicated.

In this situation, Allison felt she needed many different strategies and resources to help herself
as opposed to one strategy that John used. However, the important aspect of this code is that the
students deployed strategies and used resources through their own initiative, not at the behest of the teacher or another student.

For the category of **discovery and learning**, four codes seemed pervasive and are displayed in Table 12 below. Specifically, the codes of *invented play*, *constructing knowledge*, *trial and error* and *pulling together fragments into coherent knowledge structures* were used most often during those interviews. Thus, of the **discovery and learning** discussions found in these interviews, those four were cited most often by students as they completed their conceptual knowledge work.

Table 12

<table>
<thead>
<tr>
<th>Most Important Codes in the Discovery and Learning Category during Conceptual Knowledge Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent coded as…</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>invented play</td>
</tr>
<tr>
<td>constructing knowledge</td>
</tr>
<tr>
<td>trial and error</td>
</tr>
<tr>
<td>pulling together fragments</td>
</tr>
</tbody>
</table>

*Invented play* was used when students created an environment of play beyond that which was requested by the teacher. Students created competitions that involved many students or just played little mind games with themselves. For example, during the resizing images work, students competed to see how many problems they could answer. This competition did not begin with the teacher, but with the students. They asked that the teacher communicate the competition to the other blocks so that the competition could be across all of sixth grade. Karen discussed the competition in the interview by saying, “We had a little competition on how much we did and I think it was Becky who got the most and I got like 49... It was really close. It was really fun.”
Also, during Week 2, students demonstrated *invented play* during the percent and fraction equivalent work. After students created the percent grid, some of them chose to try to find the equivalent percent by making a picture in the percent grid instead of just shading solid pieces to look like the fraction. Madison discussed this work during the interview saying, “I think the challenging thing was today because we were… everybody was trying to make these pictures but trying to get the fraction right as well.”

Other times, the students’ *invented play* was less visible because it was a game they would play against themselves. For these games, the teacher may not have even been aware of the play if it were not for the interview when the student discussed the play. For example, Sarah noted that during the percent grid work, she would set up the screen with the most amount of grids allowed by the virtual manipulative, 1000 grids. Of course, at that point, each square within each grid is very, very small. So, she tried to click exactly where she needed to click with the very small squares. She said, “I would put it [the grids on the percent grid work] like really high and then I’d try to get it correct.”

Finally, some passages were coded as *invented play* when students’ language indicated play. For example, Jacob was discussing the percent grid work. He noted that he “we could just mess around with it.” The term “mess around” was considered a playful term that he was using to note his playful stance toward the virtual manipulative and the work. Importantly, in all of these instances, the play was instigated by the students and was not devised by the teacher.

The next code, *constructing knowledge*, occurs when students are feeling compelled to tell the story of some evolution. For example, some students tell the story of the evolution of their mastery of a concept. Other students tell the story of how they approached their work. It is a process of *constructing knowledge* and may not be a finished process. This code began with the
name ‘at first’ because many students began their story of the evolution with the word at first. It became a clue that we looked for in the transcripts. Seeing it over and over again, we initially captured it in the ‘at first’ code. Then as the weeks progressed and we were able to look across weeks at the code, we discerned that these stories that students were beginning with ‘at first’ were truly stories of the evolution of their knowledge. Thus, the code name was changed to constructing knowledge. Also, the researchers re-examined the interview transcripts for other examples of constructing knowledge that did not use the ‘at first’ words. For example, Marissa tells the story of her mastery of using proportions to solve for an unknown by saying, “Well, at first it was kind of confusing because it would give us hard ones and then along the way it was kind of fun because they gave you the steps.” This story indicates that Marissa actually had some potential breakthrough with the help of the steps offered by the Thinking Blocks manipulative. In another example, Karen discusses the percent grid work by saying, “when I first did it I thought because we were supposed to do the percent to 100 and mine was 400 so I thought I had to draw four tenths but it was really 400 percent.” In this statement, Karen is demonstrating that her beginning knowledge of the concept was insufficient and that it needed to evolve when she was asked to display a percent above 100. Matthew continues that line of thinking by saying, “trying to represent it even though it goes over 100. I wondered how do you show it past just that one square and so I kind of tried to find out.” Note that Matthew’s words do not indicate that he actually learned how to represent a percent if it is over 100%. That is an important distinction between this code and others such as pulling together fragments into coherent knowledge structures or making connections; the knowledge construction process does not have to be complete.
The third code, *trial and error*, occurred when students described a time when they made an important discovery, but it appeared accidental rather than by purposeful and thoughtful action. For example, Marissa was describing her percent grid work and said, “That one was kind of unexpected because I accidentally pushed the up arrow key and a lot of these grids just popped up and I was kind of surprised and that was kind of unexpected for me.” She was trying to solve a problem that needed more than one grid, but it was her first one to solve that needed more than one grid so she was unsure how to proceed. She does not describe her thinking as purposeful or her discovery as preplanned. Thus, this section was coded with *trial and error*. Other segments were coded with *trial and error* if students discussed just trying different ways without indicating much consideration prior to action or much reflection after the action. For example, Matthew was describing his interactions with Thinking Blocks saying, “…one other thing is that it [the Thinking Blocks virtual manipulative] changed the question sometimes. Sometimes it said write the difference, sometimes it said something else. So I was used to putting the difference and I would put that and then I got it wrong. So I was like, ‘what?’ so I tried pressing it again and I was wrong again so I finally noticed what I was doing so I could redo it.” Note that Matthew tried several times before he became reflective enough to figure out his difficulties. It was this action without much consideration that was coded with *trial and error*.

The fourth code in the **discovery and learning** category was *pulling together fragments into coherent knowledge structures*. McGuire and Rowland (1966) specifically noted that curiosity based learning enables students to pull together fragments of knowledge into more coherent structures and that was certainly evident during the conceptual knowledge work. This code was used when students demonstrated some new understanding, particularly by identifying small bits of information that they now see are connected. For example, Karen described an
important connection between decimals and percents by saying that “the percent is just like a decimal without the decimal point.” Further, John made an important connection to work that had been competed earlier in the year. Because of previous issues that students have had applying place value knowledge, the class began the year with a study of base 10 by comparatively exploring other number bases such as base 2, base 3, and base 5. John was discussing the decimal to percent equivalent work by contrasting it with the fraction to percent equivalent work. He noted how much easier the decimal to percent equivalent work was “because they are already like converted for you and they are already in base 10. While fractions can be in any base and it kind of throws you off so you have to make them equivalent and all that.” While the state standards do not require that sixth graders understand how to compare number bases, this knowledge was an important connection to help John describe why decimals and percents seem more closely related to each other than fractions and percents.

Also, students could be *pulling together knowledge* pieces from the virtual manipulatives and making connections to concepts they were supposed to be learning. For example, Jacob described the Thinking Blocks website in some detail, with examples of his problems and what he clicked. When he was asked why he was exploring, he noted that it was “because we had to figure out what it is and you didn’t already know it so it was an unknown problem. You had to figure out what the information is.” In other words, while many students struggled with the Thinking Blocks work, Jacob was able to identify exactly why the work was important, that it was helping students create a model to use proportions to solve for an unknown. In another example, Becky described how another student helped her understand the decimal to percent equivalents by connecting it to the Base Block manipulative. She said that the other student “kind of like drew a chart explaining like how it is the same its just a 10, like each bar equals 10
like 10 base blocks so when I learned how to do it I finished very quickly.” This code signifies important learning because it assists students with the organization of their knowledge, which is an important step in moving their thinking and problem solving closer to that of an expert (Bransford, Brown, & Cocking, 2000).

For the digital tools category, four codes were most discussed and are displayed in Table 13 below. Specifically, the codes of technology scaffold, technology impediment, it’s virtual and addicting were used most often during those interviews. Thus, of the digital tools related discussions found in these interviews, those four were cited most often by students as they completed their conceptual knowledge work.

Table 13

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 1</td>
<td>Week 2</td>
<td>Average</td>
</tr>
<tr>
<td>technology scaffold</td>
<td>18.0%</td>
<td>9.0%</td>
<td>13.5%</td>
</tr>
<tr>
<td>technology impediment</td>
<td>17.4%</td>
<td></td>
<td>8.7%</td>
</tr>
<tr>
<td>it’s virtual</td>
<td>7.3%</td>
<td>7.7%</td>
<td>7.5%</td>
</tr>
<tr>
<td>addicting</td>
<td>2.6%</td>
<td>4.9%</td>
<td>3.7%</td>
</tr>
</tbody>
</table>

The technology scaffold code was used students noted that technology is used as a scaffold for their learning. For example, some work had clear scaffolds designed for the manipulative. Elizabeth describes a scaffold from the Thinking Blocks manipulative that she appreciated, saying “I’d say on the thinking blocks… how at the very end it had the hint button so I just wanted to see what I have I been doing in all these different steps… So, yeah, I’d just say the hint button because then I knew what I was doing.” Clearly, the hint button on this virtual manipulative was a powerful tool that aided in Elizabeth’s understanding of the work, allowing her to make connections from the manipulative to the more abstract and symbolic mathematics.
Becky also noted a scaffold on the Thinking Blocks manipulative that allowed her to make a connection between the work she was completing on the manipulative and the symbolic algebra. Specifically, she said, “at the end I press the algebra button to see all the algebra I’ve done.”

Other scaffolds were built into the structure of the manipulative instead of being an extra button. For example, some virtual manipulatives do not allow users to move beyond a particular step until they have properly constructed the current step. The Thinking Blocks manipulative has this feature as Olivia noticed by saying, “What I thought was complicated was the Thinking Blocks because whenever you like put it like you put a block on the bottom row and you put 3 blocks on top and it said and it would say which one do you think would have the 3? And so you would have to move 2 blocks down and that was pretty confusing because that messed you up a lot.” In this situation, Olivia was noting that the Thinking Blocks site would not allow her to proceed without first properly modeling the ratio, which she had obviously not completed yet. While this scaffold confused her at first, it did not allow her to continue her misconception which is an important affordance for the manipulative.

At the beginning, all technology scaffolds were coded together into this general code. However, as the study progressed, the researchers evaluated this code because there seemed to be several types of scaffolds emerging from the students’ interview responses. Upon further investigation, some technology scaffolds were categorized more specifically. There were three particular scaffolds that also had other codes. Specifically, those scaffolds were visual modeling, material intelligence, and amplification of effort. These more specific codes are described because they help illuminate the particular type of scaffold that the students were noting.

Visual modeling occurred when students discussed the benefits of “seeing” the mathematical concept or model as an aid in better understanding the work. The visual vocabulary
was noted specifically in the students’ statements. This code was noted during the resizing images work by several students. For example, Thomas said, “I liked the resizing the images more because I mean it was more like you know you could see what you were doing… and you could see if it was right or not and it gave choices to where you can see exactly what you were doing.” Other statements were similar in that the students described being able to “see” and thus “understand” more deeply. This was particularly important during conceptual knowledge building work as this was the time that students were building their mental models of the concepts being studied.

*Material intelligence* and *Amplification of effort* are learning principles that are present in strong and compelling video games (Gee, 2003). Specifically, Gee lists 36 learning principles that are present in video games. Two of those principles, material intelligence and amplification of input, were described by students as they discussed the technology scaffold.

According to Gee (2003), *material intelligence* means that “thinking, problem solving and knowledge are ‘stored’ in material objects and the environment. This frees learners to engage their minds with other things while combining the results of their own thinking with the knowledge stored in material objects and the environment to achieve yet more powerful effects” (p. 210). For example, the manipulative used for the fraction and percent equivalent work had the number line below the models of the fraction and percent. As students shaded their percent model, the arrow on the number line would move slightly up the number line to indicate the value had increased. Students did not have to adjust the arrow, it automatically moved as the model was shaded. Karen noticed and appreciated that scaffold, saying “because it was kind of fun how if I clicked on it and moved and then click on it and move.” This freed her mind from having to consider with each click how close she was to creating an equivalent fraction and
percent. It also offered important mathematical feedback about the percent model she was building that would not have been available without the technology.

The code *amplification of effort* is based on Gee’s (2003) learning principle of amplification of input. Gee (2003) defines amplification of input by noting that “for a little input, learners get a lot of output” (p. 208). It occurs when students feel that they only have to expend a small amount of energy for a considerable gain from the manipulative. For example, Olivia noted on the percent grid work that “you didn’t have to do a lot, you just had to do the percentage and color in the box thingy [sic].” Karen discussed this scaffold with the resizing images work, noting that it “was really easy because all you have to do is zoom it out with the times [multiplier radio button] and if it was on the line or not, just drag it [the equal or not equal sign].” Both students noted the ease with which tasks were accomplished, leaving their cognitive energy available to consider the connections and implications of the work. Of course, when students are able to spend their cognitive energy on the connections and implications of their work rather than on working with physical sketches or physical manipulatives, their effort is not only amplified, their learning is as well.

Not all of the technologies used during the conceptual knowledge work provided scaffolds that the students appreciated. Indeed, at times, the technology was seen as impediment to the learning. Those discussions were coded with the *technology impediment* code. Note that this code was very small in Week 2. Indeed, during the conceptual knowledge work, the most significant *technology impediment* was noted from the Thinking Blocks virtual manipulative that was used during Week 1. For some students, the multi-step problems created issues. For example, Kevin was quite confused about the process. He said, “Well on the Thinking Blocks, they give you a question, you put the blocks down and then you have to answer another question
after you answer that question then you go back to the main question.” He clearly could not envision how the questions were related to each other or to the “main question” that he was trying to answer even though all were certainly related. The complexity of the manipulative and the lock-step manner in which it led students through their thinking caused issues for Kevin that he could not overcome. Marissa also noted how the multi-step process created challenges for her. In addition, she noted the specifics of the technology that frustrated her, noting that when she “tried to solve the problem and drag the boxes to the little rectangles… it was kind of too much.” Marissa is describing the process in which the manipulative asks the students to model the proportion with blocks. Students drag the blocks to the appropriate place based on the ratio defined in the problem. They then use a multiplier to solve for an unknown, which is the important learning for this work. However, Marissa struggled to get past building the model, which is a significant impediment to learning the underlying mathematical concepts. Other students noted particular aspects of the technology that were frustrating. For example, John noted that “whenever it said build your model on the Thinking Blocks, it asks you to put the question mark no matter what… you don’t need a question mark. You already know the answer so it was really annoying. I don’t want to put a question mark.” Again in this situation, the technology was actually in the way of John’s thinking and learning.

The third digital tools code was *it’s virtual*. This code is used when students adopt the stance that tasks can be completed more easily, quickly and efficiently if they use technology to complete it. Technology can also be described as compelling, authentic or realistic. The name for this code came from a student’s utterance during the interview. The researcher was asking students for the underlying reason that technology is better than any other tool. Marissa said, “It’s virtual!” as if it should be obvious why technology was better. For example, Marissa noted
that “When things are on the computer, it makes you more interested. On paper… you just sit there and you’re just putting all the stuff on the paper. People like it more when it is on the computer because they feel like it is better and its very fun.” In this situation, Marissa is expressing a general dislike for paper work and the converse, a general appreciation for anything digital. She also connects the use of technology with fun, which is an important connection explored more deeply in the themes. Madison was more specific with her sentiments, saying that “The Thinking Blocks reminded me a lot of drawing a model like we used to do except it was virtualized and I think it was easier than drawing the blocks out.” The ease with which students can complete the work is an important consideration for students and connects back to the amplification of effort code. Further, similar to the material intelligence code, when students spend less cognitive energy on working the model, they can spend more cognitive energy to explore the limits of the mathematics via manipulation of the model and evaluation of the results of that manipulation. Finally, Karen expressed her feelings by saying “I don’t really like the papers because… if you mess up people will know that you messed up but if it’s on the computer, only you know that you messed up.” In this situation, Karen is not only expressing her preference for computer based work, she is also giving a reason. In her view, the work on the computer offers some protection against the public embarrassment of the natural mistakes of learning. While considerable effort is made in the classroom to create a safe learning environment where mistakes are viewed not as a source of embarrassment but as an avenue to deeper learning, the age of adolescents means that students have a heightened sense of peer opinions and will work hard to make sure they are not embarrassed.

The final important digital tools code from the conceptual knowledge work was addicting. It is a behavioral addiction that they describe, as opposed to an addiction to a
substance. John noted that “your body believes that you need it [the behavior] or your brain thinks that you need it [the behavior].” Certainly, it is a behavior that you do not want to stop doing, which as Allison notes, is both good and bad. She said, “I think of addicting as a good and bad thing because it’s like fun to do so you don’t want to stop but the bad thing is, you don’t want to stop.” The determining factor of whether the addiction is good or bad is whether or not they see it as productive or beneficial. For example, Elizabeth explained, “I think how some of you were talking being addicted to technology would be that it’s like your own little world so it’s another world so if you mess up on one world you can create a whole new one and it will be perfect and stuff but it can really take up your life. You know in the classroom if you are addicted to like a game or something, that’s good because it’s academic and you’re learning and it’s productive.” In this example, Elizabeth is demonstrating a sophisticated nuance of addiction but one that was echoed from other children as well. Indeed, addiction does not have to be viewed as a negative behavior. Salen and Zimmerman (2004) contend that addiction is positive for game designers as it signals that they have created a compelling game that players do not want to stop playing. It is the compelling nature of addiction combined with the learning that they can do with the technology that students are describing as productive.

In some situations, students used the word addicting or addictive to describe their reasons for persisting or for doing more than they were required to do. For example, Kevin was describing why he completed so many of the resizing images problems and he said, “because it was fun, addictive and it was learning.” Other students did not use the word addicting, but they described behavior that met their definition of addicting. For example, Allison described her work with the percent grid by saying, “…once you told us to stop I couldn’t stop. I kept on doing it until I had to stop. But I didn’t want to. I just wanted to continue doing it because it was like
really fun.” While she did not use the word *addicting*, it was clear from her words that she met the students’ definition of *addicting*.

For the **emotional connections to learning** category, four codes were most discussed and are displayed in Table 14 below. Specifically, the codes of *feelings of competency*, *easy*, *fun* and *confused* were used most often during those interviews. Thus, of the discussions related to emotions found in these interviews, those four codes were cited most often by students as they completed their conceptual knowledge work.

Table 14

**Most Important Codes in the Emotional Connections Category during Conceptual Knowledge Work**

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
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<tbody>
<tr>
<td></td>
<td>Week 1</td>
</tr>
<tr>
<td>feelings of competency</td>
<td>8.2%</td>
</tr>
<tr>
<td>easy</td>
<td>5.4%</td>
</tr>
<tr>
<td>fun</td>
<td>7.7%</td>
</tr>
<tr>
<td>confused</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

The *feelings of competency* code was the most used code in this category. It also increased from Week 1 to Week 2. This increase is related to the increase in the *easy* code because most of the times students were discussing their *feelings of competency*, they felt the work was *easy*. This code is used when students’ discuss their understanding of the concept and specifically when students feel that they understand the concept. Sometimes, the *feelings of competency* resulted from an external measure. For example, Becky noted “I got to Level 2 Ratios and I was ahead of everybody.” But most of the students used internal measures to judge their competency. For example, Sarah said, “I knew that if I kept doing it, I would get better at it
and it was fun.” Finally, Allison offers another example when she describes how she her *feelings of competency* developed over the course of the unit. During the second week of conceptual knowledge work, students were working with percents as a particular example of ratios and proportions. She said, “before whenever it was like Target Math or something and we had to find a percent I would have trouble with that because I didn’t really get how to do percents. But since after we learned about how to figure out percents I sort of liked it because it wasn’t that complicated.” Allison is offering an important example of the competency students feel after they have worked with the concept using the virtual manipulative as opposed to only learning the procedural knowledge. Target Math is a spiral review daily warm up that is used at the school as a means to help students retain their mathematics knowledge. However, early in the year students do not know all of the mathematical concepts. So, particular concepts are pre-taught with procedural steps and the students document those steps in their mathematics journal using sample problems. They then apply that sample problem to the weekly Target Math problem to solve. This is not unlike many mathematics classes which are taught with procedural knowledge and worked examples that students use to apply to new problems. However, the Target Math work left Allison feeling uncomfortable with the depth of her knowledge. Only after she interacted with the virtual manipulatives and built her conceptual knowledge did she gain her feelings of competency.

As noted, many of the *feelings of competency* were coupled with a feeling that the work was *easy*, which was the second most important code in the *emotional connections* category for conceptual knowledge. The *easy* code was used when students said the work was easy or that they did not have to put forth much effort. Sometimes students use the word *easy* when they are describing work that is just the right amount of challenge. For example, Marissa noted that she
“really liked the resizing images because it was a lot easier and it was kind of simple.” Other terms used were “not very complicated” or “very simple” to describe the ease with which the students completed the work. While students understand that challenge is an important part of the learning process, interspersing the challenge with some work that deepens learning but still can be viewed as easy is a way for students to recommit to the learning process and not feel as if they cannot learn the mathematics.

The third code used was fun. This code captures the emotion of fun for students. It was used anytime the students said the word fun while describing the work or comparing work from different days or weeks. For example, Madison was describing why she was exploring during Week 2 and she said, “I think the thing that made me explore more was the decimals to percents because it was fun.” This quote from Madison offers readers a glimpse into the connections that can be made directly to curiosity. Exploration is one of the characteristics of curiosity. The researchers were interested in uncovering why students were curious, which was asked based on the less transparent characteristics of curiosity. Thus, fun was cited as a compelling reason that students were exploring. In other words, curiosity is directly fueled through fun.

Not all the work was fun or easy though. The final important code from this category was confused. Students described being confused by using the word confused or by describing a state of mind in which they were not sure what course of action to take. For example, Kevin described his work with Thinking Blocks and said, “I felt confused because I was reading too fast so I didn’t think I could get everything I read. Then it got easier.” Kevin was able to use particular strategies to help him through his confusion. But, while Kevin believed the work became easier, not all students discussed moving past the confusion. For example, Karen noted “today when we had to do all the extra stuff it got confusing because sometimes you forgot to do a step and you
can’t go back to look at it and it was much more confusing.” This does not mean that Karen never moved past the confusion. It only means that she did not indicate through her words that she understood. Finally, some students discussed confusion that was not necessarily with the work, but it was confusion surrounding the virtual manipulative. For example, Sarah was confused by the complexity of the Thinking Blocks manipulative and said, “What I thought was unexpected was that all the stuff that was on the Thinking Blocks. There was the read the problem, your math teacher says, problem solving steps and build your model. I feel like there should only be like 2 or 3 of those instead of just all of them because with the read the problem they had the problem, the build your model was you had to build it and then you had to put a question mark and then do all these numbers which was really confusing then you had to read what the math teacher said at the same time and then the problem solving steps which both are pretty much the same thing so I just got really confused with so much.” Students’ tolerance for the unexpected is an important construct for curiosity and was the question that Sarah was answering. Thus, it is important to note that Sarah did persist with her work in spite of the unexpected complexity of the manipulative.

While other codes existed in each of these categories during the conceptual knowledge building work, the percentage of the interview that was coded with those codes was insignificant. For example, codes such as experiment, gaps in knowledge and intrinsic reward were used but only a small percentage of the interviews each week were coded using these codes. Thus, the codes explained above within each category were deemed to be the most important codes expressed by the students.
Findings from Learning Mathematical Problem Solving Knowledge using Technology

Interviews from the Weeks 3, 4 and 6 addressed the mathematical problem solving knowledge work. Specifically, Week 3 was the interview about the Math Out Loud work, Week 4 was the interview about the mathcast work and Week 6 was the interview about the Folders of Wisdom and Knowledge work. These interviews answer the fourth research question that asks how and why students demonstrate curiosity during mathematical problem solving knowledge using technology. Table 15 depicts the data that are graphically displayed in Figure 26 above. Specifically, it lists the percent of three weeks of problem solving interviews that were coded with each category.

During problem solving work, **discovery and learning** drew even more discussion than during conceptual knowledge work. The **discovery and learning** talk was followed by discussions of **self-regulating behaviors**. A smaller portion of the interviews were spent with students discussing their **digital tools** and **emotional connections to learning**. Because of the nature of problem solving work, it is no surprise that **discovery and learning** are strongly represented. Problem solving work applies knowledge in a complex or novel way. Thus, even when students understand concepts, the application of those concepts can illuminate any misconceptions or gaps in their understanding. A more detailed examination of the important

<table>
<thead>
<tr>
<th>Category</th>
<th>Problem Solving Knowledge</th>
</tr>
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<tbody>
<tr>
<td>Self-regulation</td>
<td>25%</td>
</tr>
<tr>
<td>Discovery &amp; Learning</td>
<td>52%</td>
</tr>
<tr>
<td>Digital tools</td>
<td>13%</td>
</tr>
<tr>
<td>Emotional Connections</td>
<td>10%</td>
</tr>
</tbody>
</table>
codes in each category is necessary to draw any conclusions. Thus, each category is examined next, with the most important codes discussed and evaluated.

For the category of self-regulatory behaviors, three codes seemed to dominate the students’ discussions as displayed in Table 16 below. Specifically, the codes of leveraging resources, persistence and accepting ownership were used most often during those interviews. Thus, of the self-regulatory behaviors found in these interviews, those three were cited most often by students as they completed their problem solving knowledge work.

Table 16
Most Important Codes in the Self-regulatory Behaviors Category during Problem Solving Work

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 3</td>
</tr>
<tr>
<td>leveraging resources</td>
<td>5.2%</td>
</tr>
<tr>
<td>persistence</td>
<td>11.0%</td>
</tr>
<tr>
<td>accepting ownership</td>
<td>9.3%</td>
</tr>
</tbody>
</table>

The first two codes in the self-regulatory behaviors category were the same for conceptual knowledge work and for problem solving work. However, they were reversed for the conceptual knowledge building work, with persistence as the most important code and leveraging resources as the second code. The definitions of the codes are the same, however, it might have manifested itself slightly differently in these problem solving weeks. Therefore, if necessary, a few examples will illuminate any different nuances of the code.

The students identified some additional resources or strategies for the leveraging resources code during each week. For example, during the Math Out Loud, several students noted that when it was time to record their word story, they used self-talk as a strategy to help themselves when they were nervous. For example, Matthew said, “I just thought in my head,
that Vygotsky (1978) recognized as important for student learning. During the mathcasts, students leveraged the affordances of the digital pen technology to pause the think aloud in order to organize their thoughts or seek help. They then were able to continue the mathcast when ready. Allison noted, “I would pause the math cast. And that way there wouldn't be such a long gap and then I would think. And I would just talk out loud to myself that way, and once I got it, I would just press play.” The particular affordance of the technology allowed Allison to work through her challenges and doubts and continue to feel competent even when solving a challenging problem. Finally, during the virtual sorting work for their Folders of Wisdom and Knowledge, students noted that they used a specific resource, their co-created Folder of Wisdom and Knowledge to help them sort. Sarah described how she would use the Folder and compare it to the scenario or question on the computer “because the computer doesn't say... like it says the objectives and the things under it but it doesn't say what we did for that objective.” With this work, students had created a folder with each pocket representing one of the state’s objectives. Then inside each pocket, an envelope was created with each concept that related to the objective. For example, in Objective 1, Number and Quantitative Reasoning, one of the concepts is to generate equivalent forms of rational numbers. So, inside the objective 1 pocket would be an envelope on which the student would write ‘generate equivalent forms of rational numbers.’ Also on the envelope, the class brainstormed and documented all of the ways in which we worked with that concept in class. So, students would have written the manipulatives used during this study for fractions to percents and decimals to percents on the envelope, among many other pieces of work. These connections helped students organize all of the work accomplished during the year and offered students a glimpse into the purpose of the work. Thus, because the virtual sorting spreadsheet
only offered a piece of the organizational structure, she and other sought out the remainder of that structure by using their Folder.

The *persistence* code for problem solving work was similar to the conceptual knowledge. Essentially, students described continuing to work on a problem and not giving up. The reason for the *persistence* was different, however. With the conceptual knowledge work, students persisted in order to continue their work with the virtual manipulative or to continue to think about a problem or question that arose during the work. These reasons were also echoed during the Folders of Wisdom and Knowledge virtual sorting work. For example, Karen noted that she was struggling to identify the concept for a question but she “didn't really want to ask you [the teacher researcher], because I really wanted to find it out myself… I was like going down that list and kept on looking.” However, for the other two weeks, the source of the *persistence* seemed to be external. The work during those weeks was publicly posted online and students noted that public nature as a reason for their *persistence*. For example, Sarah was sensitive to the audience with the Math Out Loud script. She said, “I thought the script was the hardest part because gathering all that information was pretty easy like the words weren’t that hard that we had to do. But the script you had to make it all flow. You couldn’t just put it all together and say ‘tada’ because it would not make any sense. So you had to really think of how it was going to flow together so I think that was really kind of hard.” Although it was difficult, the thought of a world wide audience motivated Sarah to continue working through the script to make it flow.

Also, with mathcasts, students were clearly trying to create mathcasts that demonstrated strong mathematical thinking. They spoke many times about the pauses in mathcasts and their desire to limit those pauses. Olivia noted that she thought hard about her work “because I wanted to finish
the problem without any more pauses.” Students set high standards for themselves for these public performances, and that became evident during the persistent code.

The accepting ownership code was not present in the conceptual knowledge work but appears as a strong code during the problem solving work. When students attribute their success or failure to their own choices and abilities, they are accepting ownership. For example, during the mathcast interview, Karen noted that she was not pleased with the mathcast she did with her partner because “we missed some questions, and then I had to restate some stuff. Because we didn't plan out where to put the questions when I was talking.” She was not blaming her partner or anyone else. She was taking responsibility for the problem of not planning. Kevin also accepted ownership of his mistakes when he said “I messed up a few times on video.” Kevin was also not taking his mistakes lightly. It bothered him that he made these mistakes but still did not push blame onto anyone or anything else. Jacob also accepted ownership of his Folders of Wisdom and Knowledge work by noting that this was work that would help him in the future. He said, “…knowing that I had to like do it in the future because it's going to help me a lot. And I know that it's going to like, whatever I do and if I actually like study this and actually know it, I can get farther in life.” Certainly, accepting ownership of the learning has an important connection to curiosity and Jacob’s words offer insight into that connection. Recall that one of the important aspects of curiosity for educators is the connection to goal oriented behavior. With accepting ownership, Jacob demonstrates how students internalized the purpose for the work and aligned their goals with the goals of the work.

For the category of discovery and learning, four codes predominated during the students’ discussions as displayed in Table 17 below. Specifically, the codes of critical and evaluative thinking, gaps in knowledge, group dynamics, and social construction of knowledge
were used most often during those interviews. Thus, of the **discovery and learning** discussions found in these interviews, those four were cited most often by students as they completed their problem solving knowledge work.

Table 17

*Most Important Codes in the Discovery and Learning Category during Problem Solving Work*

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 3</td>
</tr>
<tr>
<td>critical and evaluative thinking</td>
<td>24.2%</td>
</tr>
<tr>
<td>gaps in knowledge</td>
<td>6.0%</td>
</tr>
<tr>
<td>group dynamics</td>
<td>12.4%</td>
</tr>
<tr>
<td>social construction of knowledge</td>
<td>8.1%</td>
</tr>
</tbody>
</table>

The **critical and evaluative thinking** code was the most important code over the problem solving weeks, although almost absent from the discussions during Week 4. The code manifested itself very differently in the context of discussions about Math Out Loud and virtual sorting in the Folders of Wisdom and Knowledge. Thus each of these two situations will be addressed separately.

During Math Out Loud, the students were researching a particular mathematics vocabulary word to write a word story. This research led to discussions during the interview about critical and information literacy. Specifically, students discussed critical literacy aspects such as multiple definitions of a word and evolving definitions over time. Information literacy discussions centered on comparing print based and online resources and the overall credibility of online resources. For example, Karen noted that “Everyone wanted one more… I only had one definition.” In other words, students not only understood that more than one definition existed for words, they were further asking their team members to actively seek out more than one definition so they would have choice in creating their word story. Also, several students debated
whether print based sources or digital sources were more reliable and trustworthy. Marissa said, “they [websites] might have a lot of lies and stuff about it because they are just trying to get people to use it but on a math book they might have tested it and put it in there for people to know it so it’s probably going to be… it’s going to be correct if you use a math book.” Sarah agreed saying, “if you see it in a textbook you usually you would know that it’s correct mostly because it’s approved by the state so I think it would be better for some things like some math concepts to be on the text book and not on the internet.” While this bias for print media was predominate, some students perceived that important and reliable information could be found online. For example, Thomas noted that “The Internet is full of experts and these experts will post their stuff on Google and they know what they are talking about and you can definitely tell when a website is telling the truth or being fake.” Of course, this statement led to another discussion about the ways students can determine whether a website is reliable or not. Thomas began with a general statement about looking at the information for reasonableness, saying “when the answer makes it sense or when it makes absolutely no sense.” He also noted other aspects of reliable websites such as “something like .edu or .org at the end of the URL [Uniform Resource Locator]” or “a picture of a university in like the background.” But others disagreed saying that a website could be a “scam” no matter what the URL says. Karen demonstrated a desire to use online resources but wanted some assurances that those resources were respected and approved by the teacher by saying, “I think it’s just much better and easier if every teacher makes their own website that helps them [students].” Finally, most agreed with Elizabeth who addressed the currency of information online saying, “I think it really depends on what you are researching for textbooks or computers because like Becky said, if it’s something that has been around a while, you can probably find it in a textbook but if it’s something that happened
recently, you probably want to look on the internet because chances are they might not have made a book about it yet.” These are sophisticated literacy themes and all students participated in the discussion, indicating that it was not just a few of the students who understood literacy to this depth. Interestingly, students demonstrated a preference for print based materials rather than digital resources. If digital resources are privileged in the students’ view, it was because a teacher had approved that website.

The critical and evaluative thinking code was also used during the virtual sorting work for the Folders of Wisdom and Knowledge. During this work, students engaged in critical and evaluative thinking as they made connections between mathematical concepts and as they distinguished differences between mathematical concepts. For example, several students described the process of virtual sorting by describing a process of exploration and organization in their minds. John noted that “you know we have to go through our minds and dig through and find our own information… so explore our own knowledge and [how] it's organized already by doing work and sorting.” Also Thomas described the connections he was making by saying that the work “actually kind of opens up a new portion of your mind” and then he described a process of making connections and discriminating differences between concepts. He continued, “I read the thing and it says that kind of thing in it, and I look for something with that word. So like if it says something about angles and what is the measure, and I go to measuring angles. And then I realize that's not right, now I look for something that has either the word measure or angle in it. And the way I did from there I did it kind of like that. And I never actually thought about it before.” This description by Thomas illuminates how this critical and evaluative thinking code also incorporated two other codes during the virtual sorting work, making connections and discriminating differences. The making connections code was described earlier as capturing
students connections between mathematical topics. The *discriminating differences* code was used when students discussed seeing a difference for the first time in several topics that they had previously grouped together. Together, these codes lead to the higher order thinking of the *critical and evaluative thinking* code described by Thomas. Other students were making connections between the classroom work and the mathematical concept. Recall as students created their Folders of Wisdom and Knowledge, each sixth grade math concept was written on an envelope along with all the classroom work that the students completed while studying that concept. Students discussed using their Folders and these connections when they were virtually sorting. For example, Sarah said, “…with the folder to the computer. Because the computer doesn't say... like it says the objectives and the things under it but it doesn't say what we did for that objective.” This was an example also included in the discussion of *leveraging resources* above. Indeed, Sarah used the folder as a resource to free her mind to engage in more higher order thinking.

Not only did students *make connections* between related mathematical concepts, they also began *discriminating differences* between concepts. For example, Sarah said, “Something unexpected that happened was how many --- how many angle choices there was. There was measured angles, there was classifying angles. There was a whole bunch of angles.” Kevin agreed saying, “I had an angle and I assumed it was… classifying angles. I thought it was that, and I kept looking down the thing and looking down and then I saw angle relationships and you got to be kidding me. And I clicked on it.” These students are identifying an important aspect of formal school learning that while new concepts are introduced each year, other learned concepts are also explored more deeply to reveal more complexity than originally perceived. Further, while making connections is an important part of learning mathematics, an equally important
endeavor for higher order thinking is the ability to discriminate the differences between concepts. The more students can provide both connections and differences, the more deeply they understand the topic.

The second important discovery and learning code was gaps in knowledge. This code is used when students demonstrate a gap in their knowledge. They are not necessarily making a connection to another piece of learning, they are just realizing there is more to learn. Certainly all discovery and learning codes connect directly to curiosity because curiosity has a strong connection to knowledge and higher order thinking. However, recall that the definition of curiosity surrounds a person’s ability to create, maintain and/or resolve gaps in knowledge. Thus, this code is at the heart of curiosity. Indeed, if students perceive that there is no more to learn, what do they have to be curious about? This code was not an important code in the conceptual knowledge work as students built their mental or visual models of concepts. Specifically, the models were provided for students for the most part via the virtual manipulative. However, during the application of that new knowledge with the problem solving work, students began to find areas in which their new mental models were not quite fully formed. These gaps in knowledge manifested themselves differently during the three weeks of problem solving knowledge work. For Math Out Loud, students identified times while they were writing their word stories that they “really had to think” because the information was not available to look up, but instead “had to come from your mind.” For example, Marissa noted “The hook for me was kind of hard. It was the hardest part because you had to think… you had to think about it for a long time.” Also, Madison was more specific in her reflections, saying that “The time I was actively exploring was when we were searching for examples. We had the easiest time finding the non-examples but examples for parallel, there aren’t many around now. We came up with
some pretty original stuff like the l’s in its name and the railroad tracks.” In these examples, students were demonstrating their struggles that stemmed from gaps in their knowledge of a particular concept. Indeed, there are many examples of parallel around, Madison had likely never been asked to create one on her own though which revealed her gap in knowledge.

During mathcasts, students identified the gaps in their knowledge as they tried to record their mathcast and describe their thinking. They knew that the other classmates would listen to their mathcasts and that it would possibly be posted online publicly for the world to see and hear. So, they were especially aware of trying to sound like strong mathematical thinkers. For example, Karen said “there was the point when Kevin was doing it and I was interviewing him. We -- it was a more difficult problem, and when we did it, when we had to pause it because we both couldn't figure it out. We had to -- I think we tried to figure it out in our head. Or get on a piece of paper or something… And after we were all done, the video was 10 minutes long.” Indeed, Karen was advocating using a script for mathcasts similar to the script for Math Out Loud, even though the purpose of the work is very different. She and several others wanted the script because they wanted the ability to write and think about the work, ask for assistance and look up resources without the pressure of the recording.

During the virtual sorting of the Folders of Wisdom and Knowledge, students demonstrated their gaps in knowledge in two ways. First, they discussed the difficulty of the work and of identifying the concept that aligned with the question. For example, Thomas said “the work, some of them were hard, I couldn't figure them out.” Marissa even called some of the questions “brain twisters” because she felt they were difficult. Students also demonstrated their gaps in knowledge with their vocabulary during the interview. Specifically, when students used slang, generic or inexact words for concepts instead of the mathematical terminology, they were
demonstrating a gap in knowledge. These particular gaps were coded as concept labels. For example, Jacob said, “you had to keep going back and forth between your actual folder and see what the things were. You know the things in there.” Rather than identifying specific concepts or even using the word “concepts,” Jacob used the word “things” to describe the mathematical concept, thus demonstrating a gap in his knowledge or recall. Kevin also used incorrect terminology during his discussions of the virtual sorting work. He said, “I think it had decimals and fractions and portions on it.” While decimals and fractions are certainly sixth grade mathematics concepts, “portions” was not. These concept labels did not necessarily indicate that students misunderstood the underlying mathematical concepts, only that they were not able to properly communicate that understanding.

The third important discovery and learning code for problem solving knowledge work was group dynamics. This code was used when students discussed the roles that group members played or any frustrations about group work in general. This code evolved during the two weeks of group work during the study. At first, the researchers were coding all group interactions as group dynamics. The code became large and as the coding continued, it was clear that there were two different types of dynamics occurring. The first type of dynamic was held in this code, which includes the group roles and responsibilities. Sometimes the students were just discussing each role they played, other times they were lamenting about responsibilities not fulfilled. The other type of dynamic that had been coded in the group dynamics code involved the group coming to consensus about the mathematics or communicating the mathematics to each other. These instances were recoded as social construction of knowledge, which is the next most important code in the problem solving knowledge work and are described more fully there. Note that this code was not used during the virtual sorting for the Folders of Wisdom and Knowledge.
work because this work was not group dependent. Students could and did discuss their thinking with their neighbors, but they were not dependent on group members and thus did not identify any issues with group members for this work.

The groups during Math Out Loud ranged from 4 to 6 students. Generally, there was little animosity noted among group members, possibly because there was no grade assigned to the work. Some students did voice some issues they had with group roles. For example, Becky was discussing the negotiations leading up to the recording process, saying, “when we were trying to record that day we were trying to figure out who was doing what… and then we were rearranging jobs because somebody wanted my job and they wouldn’t let me have it unless I would switch and they were all having discussions and stuff like that.” In this situation, students are unclear on their responsibility or want to change or clarify their role during the work. Notice that this discussion does not necessarily represent any conversations about the mathematical knowledge as those instances were recoded as social construction of knowledge.

With mathcasts, students were in groups of two students so the dynamics were slightly different from Math Out Loud. Even with the smaller group, some students still identified issues. For example, Thomas discussed his partnership saying “after [another student] recorded, I was interviewing him and he stopped me. It cut me off. I was going to ask him ‘are you sure you got it correct’ and… the last thing you could hear was ‘wait, wait, no’.” In this situation, Thomas was disappointed that he did have the opportunity to fulfill his role as an interviewer by asking the final question but this did not necessarily hinder the mathematical learning. Other students, however, identified benefits to the partnership. For example, Elizabeth noted that “I had [another student as my partner] and I didn't really understand… the problem. But he helped me figure it
out.” While both situations were clearly different, the dynamics of the partnership played a clear role in students’ work.

The fourth and final important discovery and learning code for problem solving knowledge work was *social construction of knowledge*. In this code, students were identifying times when the construction of their knowledge happened as they built consensus with others via dialogue and interaction with others. This code was not noted during the virtual sorting of the Folders of Wisdom and Knowledge work for similar reasons as the *group dynamics* code. Specifically, the work for Math Out Loud and mathcasts was more group centered than the virtual sorting work and thus the work lent itself to the *social construction of knowledge*. During Math Out Loud, students noted that most of the script elements could be found in print or online resources. However, the hook was a part of the script that required application of their knowledge. It was also the part of the script during which the most *social construction of knowledge* happened. For example, Olivia noted that “The hook was a bit hard like there was like a lot of, but not some very good ones and then everybody wanted their idea to be in it. And so it was very complicated.” As students were building consensus among ideas, they were also learning to communicate with each other about the essence of the vocabulary word and how their idea of a hook best illuminated that essence. Also, Elizabeth noted the difficulties of coming to consensus in her group about the hook. She lamented, “I did notice that it was unexpected that it was actually really hard to make the hook and to narrow it down to just one being in a group. So, I’d like to see maybe, I don’t think we will, if there was a way that you could do it independently, but it just wouldn’t work the same because if you have all the different ideas and stuff, you get everyone’s perspective.” In this situation, she clearly perceives value in others’ opinions and perspectives, but she also was trying to think of ways to avoid the uncomfortable
process of finding consensus. Not all groups struggled with the hook though as Madison pointed out. She noted “how fast we came up with the hook. It didn’t take us very long. I think it took us about 2 minutes to find the hook that everybody agreed on.” This group was clearly able to quickly construct the collective knowledge they needed to devise a satisfactory hook, one that communicated something important about the vocabulary word while also enticing the audience to listen.

During mathcasts, many students discussed not only their desire to help others understand their problem and their thinking but also the difficulties they had in doing so. Marissa said, “sometimes it's kind of complicated to say what you are thinking and people don't understand you as well as yourself. Because you know it and they might be kind of confused of what you are saying.” In this way, Marissa is describing the process of constructing knowledge with the world as the mathcasts are posted publicly. Sarah also discussed this aspect when she was describing her idea of a good mathcast as “when you make the other person listening understand more about your problem.” Karen also discussed her difficulties in describing her thinking process as she said, “when trying to explain it to someone on a video, it was a whole different thing.” Karen is identifying how difficult it is to communicate thinking and knowledge as learners are in the midst of forming that knowledge. While difficult, this communication is an important way for students to realize their gaps in knowledge and use their partner to help them resolve those gaps. Finally, Becky discussed a different aspect of social construction of knowledge. She and her partner used the mathcast notebook to view other mathcasts and evaluate the work of students from previous years. She said, “Well, in the book there was like, there was like people doing different kinds of questions. Each week there was someone who did a different question than the other person. So we looked in the book and we were comparing their work from whoever's work
in the mathcast.” This comparison with students thinking from previous years was a surprise benefit of using the same mathcast notebook for several years. It also demonstrates how the social construction of knowledge occurred not only with students present in the room, but also with students who no longer attended the school.

For the category of digital tools, two codes were a major source of the students’ discussions as displayed in Table 18 below. Specifically, the codes of wide audience and it’s virtual were used most often during those interviews. Thus, of the digital tools based discussions found in these interviews, those two were cited most often by students as they completed their problem solving knowledge work.

Table 18

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Week 3</td>
<td>Week 4</td>
<td>Week 6</td>
<td>Average</td>
</tr>
<tr>
<td>wide audience</td>
<td>10.4%</td>
<td>11.3%</td>
<td></td>
<td>7.2%</td>
<td></td>
</tr>
<tr>
<td>it's virtual</td>
<td>1.9%</td>
<td>4.0%</td>
<td>12.1%</td>
<td>6.0%</td>
<td></td>
</tr>
</tbody>
</table>

The first important code in the digital tools category during problem solving work was wide audience. When this code was used, students were attributing their work to the presence of a wide audience outside of the classroom. Usually, this was in reference to work that is posted online for the world to see. Students create a high standard for themselves when their work is created for a wide audience. Note that this code was not used during the virtual sorting for the Folders of Wisdom and Knowledge because that work is not posted online. During Math Out Loud, students attributed significance to the recording process in which they were creating the product that the world would hear. For example, Sarah described the challenging process of writing the script “because… we had to interpret everything in it. And we tried to like put it in
order first and then we just make it to where it flowed and it took a while.” She specifically noted that they persisted with the difficult work of pulling the script together because “we were going to record the next day.” Madison also described the importance of the wide audience during the recording process, noting that “I know a lot people are going to hear it and if I mess up I feel like I just let those ton of people down on that part.” Indeed this is an important connection to curiosity because students are discussing their high standards for their learning and reason for persisting to the wide audience. So, students are setting their own goals, persisting in the face of challenges, and learning at deep levels, all of which are characteristics of curiosity inspired learning, due to the wide audience.

During mathcasts, students described the communication process of the mathcast and their desire to “make a strong mathcast” which meant that they would “make the other person listening understand more about your problem.” In fact, several students expressed a desire to script their mathcast before they recorded. For example, Karen said, “I think we should have done it on a piece of paper first... and then on the special notebook… because I was like pausing and then I was trying to figure on it out in my head... so I got messed up lots of times.” Olivia also noted the importance of completing a mathcast “without any more pauses” because of the permanency of the recording. Finally, Sarah noted that the unexpected part of the mathcast which was also frustrating was “when I was recording it, I thought it sounded like really good and I was like really proud of myself. I was like yay, then I heard and I stuttered a whole bunch.” She was demonstrating the importance that she placed on the recording and how disappointed she was when the recording did not live up to her expectations. Again, these self-initiated goals, the persistence to reach the goals and the deep learning all connect to learning with curiosity.
The second important code in the **digital tools** category for problem solving knowledge was *it’s virtual*. This code was also used during conceptual knowledge work and it manifested itself similarly during these problem solving weeks. For example, during Math Out Loud, Olivia was discussing the research she was doing for her group’s word story and said, “You said we could use the laptop so that would be a little easier and that helped me keep going.” During mathcasts, Thomas discussed the technology of the digital pen. He said, “I just loved doing the mathcast. I loved the pen and technology and when technology is involved… you can actually say what you want to say with technology.” Finally, with the virtual sorting work for the Folders of Wisdom and Knowledge, students noted that the technology afforded them the ability to work at their own pace. John said,

> It’s more efficient than having everyone answer as a class because you have to wait for everyone to answer. And so like what is this question, and when you have virtual sorting, everyone is at their own pace. People who are fast they don't have to wait on the class, they just go with it and answer the questions as fast as they can. And the people who need a bit of time to work things out and can go slower and it helps them and they understand it.

As with the *it’s virtual* code during conceptual knowledge work, students made connections to the work being easier, more fun or more efficient when using technology to complete the work.

For the category of **emotional connections to learning**, two codes predominated during the students’ discussions as displayed in Table 19 below. Specifically, the codes of *self conscious* and *frustrated* were used most often during those interviews. Thus, of the **emotional connections to learning** discussions found in these interviews, those two were cited most often by students as they completed their problem solving knowledge work.
Table 19

**Most Important Codes in the Emotional Connections to Learning Category during Problem Solving Work**

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 3</td>
</tr>
<tr>
<td>self conscious</td>
<td>6.2%</td>
</tr>
<tr>
<td>frustrated</td>
<td>7.4%</td>
</tr>
</tbody>
</table>

The first important code in the *emotional connections to learning* category for problem solving work was *self conscious*. This code was used when students noted that the work made them feel overly conscious of themselves or their mathematical thinking. Note that this code was not used during the virtual sorting task for the Folders of Wisdom and Knowledge because that work was more individual work and so the cost of making a mistake was significantly lower. As previously noted, the *wide audience* of the Math Out Loud and mathcast work helped students set high standards for themselves and their work. However, those same aspects made students feel *self conscious*. During Math Out Loud, Matthew noted that “I always get nervous that I’m going to mess up.” Marissa also described her feelings by saying, “sometimes when I hear myself on recordings, I think I sound very high and it sounds really weird to me so I like get very nervous and I’m like I start to stutter. That happens a lot… and it kind of makes me ashamed and it makes me like panic. It’s like very embarrassing.” Also, during the mathcasts work, students discussed their unease with their mathematical think aloud. Elizabeth said, “if you are having trouble with a problem it gets a little embarrassing and uncomfortable.” Karen agreed, even though she noted that “it's kind of normal” to “mess up.” This code of self-conscious has important implications for curiosity. Certainly, anxiety would negatively correlate with both learning and curiosity. However, small amounts of anxiety were tolerated by the students
because the public nature of the work offered a broader purpose to their learning. In other words, this work with its public nature and wide audience offered students the opportunity to set goals for themselves. The goal of this work was not necessarily defined by the teacher or the mathematical community, although those audiences had weight in the students’ minds. Further, when students feel self-conscious, they work to resolve that feeling. The resolution of their self-consciousness comes from more deeply understanding the mathematical concept and is directly related to the definition of curiosity that specifies a resolution in a gap in knowledge. Therefore, while self-conscious might typically be considered an emotion that stifles curiosity, students could still be curious even when feeling self-conscious.

The second important code in the **emotional connections to learning** category for problem solving knowledge was *frustrated*. This code captured students’ frustrations as they completed the work. Notice that this code was not present during the Math Out Loud or mathcast work, but only appeared during the virtual sorting for the Folders of Wisdom and Knowledge. Some students noted that the work itself was difficult and they became frustrated with it. For example, Allison discussed the questions themselves and her ability to sort them correctly. She admitted that some were obvious but “the ones I didn't know those were challenging, like a lot. And then I just got mad and just went through it and clicking everything.” Other students became frustrated with the spreadsheet software that was used to house the work. For example, Elizabeth became frustrated because the screen would scroll sideways and at first she did not know how to fix it. She was also frustrated with the amount of scrolling the work required in general. She said, “it took so much scrolling down. So unnecessary. And then click it and then scroll down again and then scroll to the next question. And then the screen would go sideways.” This frustration with the software was more prominent during the interview than any frustration with the work.
itself. It is likely due to the fact that the software is being used for work that it was not originally designed to house and that the students are relatively unfamiliar with the functionality of the software. Similar to the confused code and the self-conscious code, the presence of negative emotions does not necessarily indicate that curiosity was stifled. Indeed, it can be the impetus for curiosity itself as students work to resolve gaps in knowledge to rid themselves of the negative emotion.

While other codes existed in each of these categories during the problem solving knowledge work, the percentage of the interview that was coded with those codes was insignificant. For example, codes such as experiment, easy and flow were used but only a small percentage of the interviews each week were coded using these codes. Thus, the codes explained above within each category were deemed to be the most important codes expressed by the students.

**Findings from Learning Mathematical Procedural Knowledge using Technology**

The interview from Week 5 addressed the mathematical procedural knowledge work, Study Buddies™. This interview answered the second research question that asks how and why students demonstrate curiosity during mathematical procedural knowledge using technology. Table 20 depicts the data that are graphically displayed in Figure 26 above. Specifically, it lists the percent of the procedural knowledge interview that was coded with each category.

The **digital tools** category eclipsed all other categories during this interview, followed by the **self-regulated behaviors** category and the **discovery and learning** category. The **emotional**
Table 20

Percent of Procedural Knowledge Work Interviews Coded with each Category

<table>
<thead>
<tr>
<th>Category</th>
<th>Procedural Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-regulation</td>
<td>17%</td>
</tr>
<tr>
<td>Discovery &amp; Learning</td>
<td>14%</td>
</tr>
<tr>
<td>Digital tools</td>
<td>63%</td>
</tr>
<tr>
<td>Emotional Connections</td>
<td>6%</td>
</tr>
</tbody>
</table>

categories to learning category was the smallest category represented. This interview represents the only one in which discovery and learning is not the most discussed category.

For the category of self-regulatory behaviors, two codes predominated during the students’ discussions as displayed in Table 21 below. Specifically, the codes of persistence and leveraging resources were used most often during those interviews. Thus, of the self-regulatory behavior discussions found in these interviews, those four were cited most often by students as they completed their procedural knowledge work.

Table 21

Most Important Codes in the Self-regulatory Behaviors Category during Procedural Knowledge Work

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 5</td>
</tr>
<tr>
<td>persistence</td>
<td>8.4%</td>
</tr>
<tr>
<td>leveraging resources</td>
<td>8.2%</td>
</tr>
</tbody>
</table>

The persistence and leveraging resources codes are both similar to those noted in the conceptual knowledge work and the problem solving work. The codes also manifested themselves similarly during the procedural knowledge interviews. An example of persistence with the Study Buddy™ was when Marissa said “I could not get this question right at all. And I
sat there for like five minutes trying to figure out what the question was -- what the answer was. And I kept reading the whole entire question, what they were asking me, and I looked at the answers and when I got this piece of paper out and get the answer, and it wasn't there. So I kept doing it and kept doing it. And I looked down and it was on there, but I had to make sure, and I did it again and I got the right answer.” Certainly, this was a long process for and as with the other categories, Marissa was demonstrating that she would continue working even though the work was difficult. The main strategy that students discussed using during the leveraging resources code was using paper for calculations or drawings. For example, Kevin said “I got the paper… I drew it out one, two, three, four, five and the answer was right there.” Again, these strategies were not required nor were they directed or suggested by the teacher. They were initiated by the student when the student believed that he/she would benefit from such a strategy.

For the category of discovery and learning, two codes predominated during the students’ discussions as displayed in Table 22 below. Specifically, the codes of trial and error and constructing knowledge were used most often during those interviews. Thus, of the discovery and learning discussions found in these interviews, those two were cited most often by students as they completed their procedural knowledge work.

Table 22
Most Important Codes in the Discovery and Learning Category during Procedural Knowledge Work

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 5</td>
</tr>
<tr>
<td>trial and error</td>
<td>10.7%</td>
</tr>
<tr>
<td>constructing knowledge</td>
<td>4.2%</td>
</tr>
</tbody>
</table>
The codes of *trial and error* and *constructing knowledge* were also seen during the conceptual knowledge work as important codes in the *discovery and learning* category. These codes manifested themselves similarly during students’ procedural knowledge work. For the *trial and error* code, students learn not through purposeful experimentation, but through less structured discoveries that can even occur by accident. For example, Jacob discussed the study mode of the Study Buddy™ work. In this mode, students are asked questions and given immediate feedback. If the student answered incorrectly, the device would indicate the student was incorrect and offer another opportunity to correctly answer the question. The student would not proceed to the next question until the answer was correct. Jacob said, “if you get the question wrong, it keeps you on the question until you get it right. And usually when I went to study it, I kept getting them all wrong until the last answer.” This statement shows that Jacob could have been simply memorizing the answers to the questions and learning little. It also shows little indication of forethought or purposeful action and was thus classified as *trial and error*. Similarly, the *constructing knowledge* code for procedural knowledge mirrors the *constructing knowledge* code for conceptual knowledge. Specifically, this code demonstrates students’ evolution of their mastery, although the evolution might not yet be complete. For example, Elizabeth discussed the tutorial mode of the Study Buddy™. She uses that mode after she has mastered a test because “sometimes if I don't really understand what it is, it really helps me.” For Elizabeth, she might have the procedural knowledge mastered, but if she does not feel confident in her conceptual knowledge of the work, she finds the tutorial helpful.

For the category of *digital tools*, four codes predominated during the students’ discussions as displayed in Table 23 below. Specifically, the codes of *seeing possibilities, fun versus learning, user inexperience*, and *disappointment with technology* were used most often
during those interviews. Thus, of the digital tools discussions found in these interviews, those four were cited most often by students as they completed their procedural knowledge work.

Table 23

*Most Important Codes in the Digital Tools Category during Procedural Knowledge Work*

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
</tr>
</thead>
<tbody>
<tr>
<td>seeing possibilities</td>
<td>21.6%</td>
</tr>
<tr>
<td>fun vs learning</td>
<td>20.3%</td>
</tr>
<tr>
<td>user inexperience</td>
<td>14.5%</td>
</tr>
<tr>
<td>disappointment with technology</td>
<td>13.7%</td>
</tr>
</tbody>
</table>

All of the important digital tools category codes can be viewed as a cohesive whole, communicating students’ dissatisfaction with the Study Buddy™ technology. The first important code in the digital tools category for procedural knowledge is seeing possibilities. This code was used when students adopted a prosumer stance (Tapscott & Williams, 2006). A prosumer is a consumer who improves, changes or adapts existing works or products to incorporate his/her own tastes. In this interview, students were discussing the Study Buddy™ device and its potential with certain adaptations. For example, Thomas said,

> Well, Study Buddies™, I enjoyed them but I also don't at the same time. It would be nice if they were interactive and not just a digital textbook… It doesn't do anything fun, it's just answer questions. It mean, it would be more fun if it was a kind of video-game style. It would have a certain thing and ask you a problem based on the problem and information instead of one, two, three, four, and a, b, c, d and blah, blah. That, it's not exactly fun.

Karen agreed and also had some specific ideas such as

> I have like an idea that can really help to be an actual video game, a video game but doing our studies and all of that stuff. Like when we have a little [Nintendo] DS or might have
like a little pen. And you might want to do, after you solve the problem you may have a point or something. Like -- like if you want -- like if you try to make a triangle. And you make the triangle and you get two points and if you answer three questions. Yeah, I think that would be better than just answer questions.

Olivia even suggested that since “no one likes the buttons on it,” a “touch screen” would be a good option. All of the students were eager to improve the product with different ideas but initially they disagreed on exactly which improvements would be best. Ultimately as the interview progressed, they agreed that there could be a good balance between the mathematics and the fun. Thomas suggested this balance saying

Math moodle [the students call their learning management system math moodle] games are fun but also you have to do the math to be able to play the game… the game is what makes the math fun. Because you want to get to the next level of the game you’ve got to complete the right amount of questions. You have to answer the questions correctly. And it's like -- well, you know, kind of like a cause and effect thing. You’ve got to answer the question to move on to play the game. I mean it's like one thing leads to another. I mean it's not all game, it's not all work. It's right in the middle where it's fun and interactive.

This “right in the middle” suggestion was also an important component of the fun versus learning code, the second most important code in the discovery and learning category. Students in this code grappled with the desire for fun and the need for serious mathematics homework in order to learn the required concepts. Sarah noted “the thing is you can't really have it just like a video game. Then you wouldn't have any real learning purpose with it.” Olivia also initially believed that fun should be separate from learning as evidenced when she said “I don't think you should put video games in a homework. It takes the study out of buddy. Then it would just be
buddy and not study.” Students noted that the device should not be too much like a game because “people would get distracted and they would probably go off and not even do the work part.” This was an interesting and new stance because in the conceptual knowledge interviews, students specifically noted that they continued working on their virtual manipulative because it was fun and it was learning. Eventually during the procedural knowledge interview, students began to see that fun and learning could be combined as noted in the discussions of the seeing possibilities code. The fact that the students view the technology as limiting and do not believe it is fun has significant implications for curiosity. Certainly, the students during all the other weeks of the study have attributed their curiosity to times when they could explore, not respond in a lock step manner. Further, an indication of the curiosity and the exploration has been the feeling of fun. Thus, both of these factors indicate that curiosity may not have been fostered during this work. Further, as previously noted, this is the only knowledge work in which the discovery and learning category was lower than another category, another indication that curiosity was not as prevalent during this work.

The third important code for the digital tools category during procedural work was user inexperience. This code was used when students were voicing concerns about the technology that could be directly attributable to their inexperience with that particular hardware or software. During the interview, students discussed difficulties finding the power button on the Study Buddy™, inserting the cartridge, and charging the device. These difficulties were specifically noted as issues that students had early in the process of working with the device. In other words, as the students gained experience with the device, these issues disappeared.

The fourth important code in the digital tools category for procedural knowledge was disappointment with technology. This code was directly related to the seeing possibilities code.
Indeed, students saw possibilities because they were disappointed with the device. For the 
disappointment with technology code, Karen noted that the device is “a study but it’s not really the buddy.” Karen was indicating that certainly the device helped her study and learn but that it did not provide any of the emotional or learning supports of a friend or buddy. Thomas also noted “I didn't like it as much as I thought I would. I tried it out and yeah, it's ok, but I am more of a modern technology kind of thing.” While this code led the seeing possibilities code, students spent much more of their time during the interview using the prosumer stance rather than simply complaining about the device. The fact that students adopted the prosumer stance rather than a passive stance signifies that they prefer the active exploration or curiosity infused role of the learner rather than the passive drill and practice role of learning. This could also be more evidence that students were regularly in a state of curiosity and desired to continue its reciprocal nature even during homework. Thus there is more evidence that the first research question regarding whether students demonstrated curiosity can be answered in the affirmative. It also offers potential evidence for curiosity’s reciprocal nature, the fourth aspect of curiosity’s relevance to educators.

For the category of emotional connections to learning, two codes predominated during the students’ discussions as displayed in Table 24 below. Specifically, the codes of social responsibility and novelty were used most often during those interviews. Thus, of the emotional connections to learning discussions found in these interviews, those two were cited most often by students as they completed their procedural knowledge work.

The most important code in the emotional connections to learning category for procedural knowledge work was social responsibility. This code was used when students
Table 24

*Most Important Codes in the Emotional Connections Category during Procedural Knowledge Work*

<table>
<thead>
<tr>
<th>Percent coded as…</th>
<th>During…</th>
</tr>
</thead>
<tbody>
<tr>
<td>social responsibility</td>
<td>7.7%</td>
</tr>
<tr>
<td>novelty</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

identified their responsibilities as it related to the care of the Study Buddy™ and the process to take it home and return it the next day. For example, Elizabeth noted that it was unexpected “the responsibility it took to not only study but to bring it back the next day” so that another student could take it home and study. John also noted that the student who used his Study Buddy™ the night before had “left it uncharged and left the bag a mess.” This shared responsibility arose because we only have a limited number of devices and students check them out on a rotating basis. So, if a student forgets the device or does not care for it properly, it negatively affects other students. The code was also used when students were demonstrating appreciation for the technology that is used for learning mathematics and the desire to not appear greedy. For example, Madison said,

I am not saying that anyone here is ungrateful for anything. But you guys have got to be kidding me. You guys want all of these extra features that can cost like at least 100 bucks a piece… There is like 65 kids in this grade and who knows how many more are in the next grade that will have to use this. You have to think if someone loses it, if it breaks, or something happens to it, how much money is it going to cost to fix it? Or to at least buy a new one.
These statements demonstrate that students are thinking of others and the greater good as they work to be responsible with the device and also make sure they are grateful for the ability to use technology as they study.

The second important code in the emotional connections to learning category for procedural knowledge was novelty. Although a small percentage of the entire interview, it was the first and ultimately the only time that students discussed novelty during the study. The novelty code was used when students noted some initial interest but that the interest waned over time. For example, Matthew said he explored “When I first got it, and now I don't explore anymore, I just do my work.” Similarly, John said he explored “when I first got it because it was a new thing and interested me.” He continued that he no longer explores because he “already know its ins and outs.” In other words, the design of the Study Buddy™ is not conducive to long term exploration which is an unfortunate situation for curiosity. Indeed curiosity is dependent on the ability to explore. Thus, this novelty code has negative implications for curiosity.

While other codes existed in each of these categories during the procedural knowledge building work, the percentage of the interview that was coded with those codes was insignificant. For example, codes such as gaps in knowledge, self evaluation and going at own speed were used but only a small percentage of the interviews each week were coded using these codes. Thus, the codes explained above within each category were deemed to be the most important codes expressed by the students.

Findings across Knowledge Work

In the first section of findings, the interviews were segregated by the type of mathematical knowledge in order to address the research questions. The data were further
subdivided by category and then by code to communicate the findings. In this section of the findings, the data were turned to view by category across all types of mathematical knowledge as depicted in Figure 27. From this view, the four categories are discussed and the three themes that emerged are discussed.

![Figure 27. Graphical representation of findings across knowledge work.](image)

**Self-regulatory Behaviors**

The important **self-regulatory behaviors** were consistent across the entire study. Specifically the codes of *persistence* and *leveraging resources* were seen as important codes during all types of mathematical knowledge work. An additional important code of *accepting ownership* was also seen during the problem solving work. The percent of the interviews that were coded in the **self-regulatory behaviors** category was relatively consistent across the study as well. The largest amount of discussion about **self-regulatory behaviors** occurred during problem solving work. This increase in **self-regulatory behaviors** is not a surprise for problem solving work as this work is less structured than the other type of work. Thus, the work itself
calls for students to heighten their self-regulatory behaviors in order to be successful. While the converse would seem reasonable, it did not occur. One might think the procedural knowledge work, because of its structure, would have the least amount of self-regulatory discussions. However, the procedural knowledge work was the only work in which a negative self-regulatory behavior was coded. Specifically, the code of lack of purpose or organization was coded only during the procedural knowledge work. Thus, while the self-regulatory behaviors were coded more often during procedural work than during conceptual knowledge work, not all of the discussions indicated positive or productive self-regulatory behaviors during the procedural knowledge work. Finally, this category has direct connections to curiosity’s connection to education with its goal oriented behavior and persistence. However, this category of self-regulatory behavior indicates that there are many behaviors that students must use to regulate themselves and be successful in learning. Thus, perhaps the literature too narrowly views the self-regulatory behaviors that link to curiosity. A broader view of behaviors that assist learners in maintaining their curious state is likely warranted.

Discovery and Learning

The discovery and learning category was the highest during problem solving work. Similar to self-regulatory behaviors, this increased awareness of discovery and learning is expected during work that purposefully stretches students’ knowledge of a concept. It is also lowest during procedural knowledge, which is also expected. Work completed during procedural knowledge should be a review of concepts that students have learned in class. There was also very little crossover between important codes during each type of knowledge. The structure and purpose of the work is very different for each type of knowledge and thus explains the fact that
important codes did not readily transfer from week to week. For example, problem solving weeks were saturated in group and social learning activities that were not present during conceptual knowledge and procedural knowledge weeks. Therefore, the only crossover of important codes existed during the conceptual and procedural knowledge weeks. Specifically, the trial and error and constructing knowledge codes were both considered important codes during conceptual and procedural work. These two codes were present during the problem solving knowledge weeks; they were just not as significant as the codes discussed above for those weeks. In fact, trial and error and constructing knowledge were the only two discovery and learning codes that were present across all of the types of mathematical knowledge, making them an important part of the themes discussed below. Finally, the procedural knowledge work was the only type of knowledge in which discovery and learning was not the most significant category. This is important because the interview questions did not ask for students to describe their learning, but rather solicited descriptions of students’ curiosity. Students themselves made the strong connections between their curiosity driven behaviors and the mathematical learning during conceptual knowledge and problem solving knowledge work but not during the procedural knowledge work.

**Digital tools**

Digital tools eclipsed the conversations during the procedural knowledge week, to an extent that it could be considered a distraction to the discovery and learning, which should be at the core of all the knowledge building work. Further, the important digital tools codes during the procedural knowledge week were codes that were not shared as important codes during the conceptual knowledge and problem solving knowledge weeks. The conceptual knowledge and
problem solving knowledge weeks did share the *it’s virtual* code. Importantly, this code was also identified in the procedural work, but was overshadowed by the discussions of *seeing possibilities* and *disappointment with technology* during the procedural work. The other code that was present during all types of knowledge work was *technology scaffold*. Both of these codes are explored more deeply in the themes discussed below. Because this is the first study to examine curiosity within a technology-rich learning environment, these digital tools are not seen in other curiosity studies.

*Emotional Connections to Learning*

The emotional connections to learning category was highest during conceptual knowledge work. The conceptual knowledge work was also the only time that this category was not the lowest among all categories for a particular type of knowledge work. This could be due to the fact that the conceptual knowledge work did not require as much cognitive energy as the problem solving knowledge work. Also, as previously mentioned, the procedural knowledge work was eclipsed by discussions of the technology. Interestingly, there were no emotional connections to learning codes that were used consistently across all weeks. In other words, each type of knowledge work seemed to evoke different emotions from the students. The particular emotion evoked by learning is likely not as crucial to curiosity as other factors. For example, certainly positive emotions such as *fun* or *feelings of competency* seemed to fuel curiosity. However, just the presence of negative emotions did not necessarily mean that curiosity was stifled. Even though anxiety is negatively correlated with curiosity, several emotions that are similar to anxiety, such as *self-conscious* or *confused*, were noted without a significant decline in curiosity. This could be because other factors mitigated the decline of curiosity. Indeed, the
literature does not indicate that all the characteristics of curiosity must be present at all times. Thus, it appears that as long as there are mitigating characteristics for curiosity to flourish, one aspect, such as an anxious emotion, will not necessarily stifle curiosity.

Themes

The themes that were identified during the study were derived from the codes used consistently across all knowledge work. Themes also crossed all categories. Three themes were identified during this study: 1) Digital play; 2) Welcome and unwelcome scaffolds; and 3) Action is power; Power follows ideas.

Digital Play

The digital play theme began with a study of the it’s virtual code. Recall that this code was used when students adopt the stance that tasks can be completed more easily, quickly and efficiently if they use technology to complete them. Technology can also be described as compelling, authentic or realistic. In describing their it’s virtual stance, students noted the reasons for the stance was that technology is fun and they enjoy exploring with technology. For example, Marissa described it as “virtual to me… it is very fun and what’s work? The pencil and paper.” Elizabeth agreed, saying “… it’s really fun. But when you put learning to it and you actually use it for something, it becomes a very productive… win-win situation.” Also, students noted that they enjoyed exploring with technology. For example, Thomas noted that “kids are more open to the computer and they’ll like explore around with it… Whereas kids, they’ll like explore and explore and explore, personalize stuff… So, kids explore on a computer more than adults do.” Madison agreed, saying “kids… have an easier time understanding computers and
how they work and exploring them than some adults do.” Of course, this exploration is a direct connection to curiosity as one of the characteristics of curiosity is exploration. Thus, from the beginning, it’s virtual, play and curiosity all appeared to be strongly connected.

As I evaluated the it’s virtual code and the ways in which the students discussed using the technology, I sensed a strong idea of play. While students are not using the word play, the concept of play is inherent in their words. Specifically, the definition of the word fun that the students used many times includes the word playful (Merriam-Webster, n.d.). Further, explore is defined as becoming familiar by testing or experimenting (Merriam-Webster, n.d.). It is certainly an inherent part of curiosity, but it also a way to play. It was important though to find a definition of play to begin to bring some structure to this theme. Salen and Zimmerman (2004) define play as “free movement within a more rigid structure” (p. 304). This free movement allows for the exploration to which students were referring and certainly fun or pleasure is the emotion produced by play (Salen & Zimmerman, 2004). Thus, it seemed that the it’s virtual code was referring to a student’s state of play, specifically play using technology and I began calling it digital play.

To further support this emerging theme, I began to study the characteristics of play or the nature of play. Additional connections were made when the types and nature of play were explored more deeply. Salen and Zimmerman (2004) offer three categories of play. They begin with their most narrowly defined category, game play. In this category, games are seen as rule based, formalized interactions between players. Games are also distinguishable from the other categories of play because games have goals and quantifiable outcomes while the other categories of play do not. The next category is called ludic activities. It is broader and encompasses games as well as other play behaviors. Examples of ludic activities are less
structured play behaviors such as bouncing a ball against a wall or children playing on a swing set. The broadest category of play is called being playful. When being playful, people can play with language, dress or social norms. The only requirement is that “the spirit of play infuses otherwise ordinary actions” (p. 303).

These categories of play supported other codes found in the study and further supported the emerging digital play theme. For example, there were no games officially included as a part of this study. However, some students created their own games during the conceptual knowledge work which fit Salen and Zimmerman’s (2004) definition of games, as evidenced in the invented play code. For example, in one situation students decided to have a competition to see who could complete the most resizing images problems. Jacob described this game saying “I think it was [resizing images] because me and [another student] did the most in our group. We had both 70 and we were I think we did more than we were supposed to because everybody wanted to see how many we could do at once.” Also, during their fractions to percents work, some students tried to create a picture in their percent grid while creating an equivalent percent to the given fraction. Madison described this game by saying “I think the challenging thing was today because we were… everybody was trying to make these pictures but trying to get the fraction right as well. When they were done they were trying to make pictures.” These games have a goal, albeit one set by the students rather than the teacher. The goals for these games were coded in a self-regulating behaviors code called initiating behaviors, which was a minor code identified during both the conceptual knowledge work and the problem solving knowledge work. The games also both have a quantifiable outcome, another of Salen and Zimmerman’s (2004) defining characteristics for games. For the resizing images competition, students kept tally marks to quantify their work. For the fractions to percents pictures, students could quantify their answer
by ensuring that the percent picture they built was equivalent to the given fraction. Thus, the data were supporting that play was occurring during students’ learning, but I continued to examine the other categories of play in order to further substantiate the theme.

During the study, students also demonstrated ludic activities as they interacted with the technology and the mathematics. A more detailed example of ludic activities will help illuminate.

Think of bouncing a ball against a wall… In experiencing the play of the ball, the player is playing with structures such as gravity, the material identity of the ball, the architectural space, and his or her own physical skill in throwing and catching. To play with the ball is to play with all of these structures, testing their limits and boundaries, finding ways of moving around inside them. (Salen & Zimmerman, 2004; p. 304).

While working with the conceptual knowledge virtual manipulatives, students were certainly involved in ludic activities. They were playing with the limits of the mathematical concepts under study in an environment that offered mathematical feedback to their pursuits. These activities were particularly evident in the material intelligence code. Recall, this code was used from Gee’s (2003) learning principles from video games. Gee describes the material intelligence learning principle in both video games and in a more traditional learning environment. Gee writes, “In a video game, objects and artifacts store some of the thinking and knowledge a player gains. So, in fact, does the environment the player moves through… In video games players learn how to ‘read’ the physical environments they are in to gain clues about how to proceed through them” (p. 109). For example, Karen describes the Fractions to percent manipulative and its material intelligence to model the fractions on the number line. She said, “Because it was kind of
fun how if I clicked on it and moved and then click on it and move.” Gee continues to describe this principle by connecting it to more traditional science and mathematics concepts, writing,

For example, just staring at and playing with pendulums in the real world is not actually a good way to ‘discover’ the laws of the pendulum’s movement. Galileo actually discovered these laws not by staring at a swinging chandelier, as the myth has it, but by using geometry and drawing, on paper, arcs and circles and paths of movement along them and figuring out their geometrical properties. Geometry is a powerful tool that stores much knowledge and skill that the learner does not have to invent for him- or herself. (p. 110).

Of course, the problem with this argument for geometry’s material intelligence is that the novice has little visibility into those powerful tools of geometry. Indeed, much formal learning is required before learners can access those geometrical properties of arcs and circles that Galileo used. However, as the digital play theme emerged, students were describing how technology increased the visibility of mathematical properties so that they could play with the concepts as they learned their limits. For example, Sarah noted that “with resizing the picture… I could like see it being equal.” In this situation, Sarah is describing her play with proportions in a way where the visibility of the powerful properties of proportions were illuminated. This code was titled visual modeling and was used when students discuss the benefits of “seeing” the mathematical concept or model as an aid in understanding. It was a code that was encompassed as a technology scaffold and with the technology scaffold code was an important code during the conceptual knowledge weeks. In another example, Marissa described the environment that offered her clues about the way to proceed. In her work with the percent grid, she was presented with a problem to model that was greater than 100% requiring more than one hundreds grid to model. She said, “I had a big number… I was kind of freaking out about it because I only had like one grid and I was
like I don’t know where it is and then I clicked on it [the up arrow button] on accident and I was like relieved.” She said, “I accidentally pushed the up arrow key and a lot of these grids just popped up and I was kind of surprised.” Marissa’s discovery was coded as trial and error because of the almost accidental nature of her learning. While it seemed to be accidental to Marissa, the environment that was rich with material intelligence actually offered her clues as to her path.

Indeed the digital play with virtual manipulatives that offer material intelligence is a powerful alternative to physical manipulatives that offer more limited mathematical feedback. Pea (2004) notes that one of the benefits of technology-enhanced scaffolds is that the technology focuses learners attention away from unnecessary or even misleading activities. Pea’s findings are similar to Gee’s (2004) material intelligence and the findings from this study as well. For example, base 10 blocks are a common manipulative used by mathematics teachers. These blocks have some material intelligence built in to their structure as a student can line up ten of the ones cubes which match the length of the tens rod. However, when these base 10 blocks are used, many students like to play with them by building towers with the blocks. This building activity offers students spatial feedback, but no particular feedback about place value, which is the reason the blocks are in use. In contrast, students’ play on the base blocks virtual manipulative offers mathematical feedback directly related to place value. For example, when students add more then 10 ones blocks, the number disappears indicating that the value that the student has modeled cannot be directly represented in Arabic numerals using base 10. This mathematical feedback offers considerably more visibility into the powerful mathematical concepts that students can then access to problem solve in other applications. This example also highlights the importance of digital play versus physical or real world play. In other words, the


Digital play offers significantly more productive and pointed learning opportunities for students. Play is important for learning (Vygotsky, 1978) whether it is with digital tools or real world tools. However, the play is made more purposeful and exciting to students because of the improved material intelligence of the digital tools versus real world tools. In other words, digital tools allow students to play with the concepts being learned rather than being led through a concept. Further, the digital tools offer more visibility into the mathematical concept being studied, which significantly improves learners’ abilities to capture the essence of the concept.

Salen and Zimmerman’s (2004) have one more category of play, being playful, which is the broadest of the play categories. I also examined the data for this category of play even though it was very broad because I believed it was important to identify all of the categories of play to support this theme. This playful stance is very evident in the fun code. Students used the word fun when referring to the work. They also used vernacular language. For example, Jacob said, “I think the percent grid because whenever we went to explore we could just mess around with it.” Students also used word play during their Math Out Loud word story script writing. For example, the group that was researching the word parallel created a hook that also encompassed their example, train tracks. They called the railroad the “parallel-o-rail”, demonstrating their playful stance towards the language and the mathematical concept. Thus, all of Salen and Zimmerman’s (2004) categories of play were present in the study, lending viability to the digital play theme.

Once the theme of digital play was supported, I began to examine strong connections between play and curiosity that might offer insights. These connections emerged from a study of the nature of play. I began with Salen and Zimmerman (2004) who had offered strong guidance in the definition and categories of play. “Play is an expression of the system, one that takes
advantage of the space of possibility created from the system’s structure” (Salen & Zimmerman, 2004; p. 304). This was a broad description of the nature of play that did not seem to offer enough specificity to capture the essence of what the students described. So, I then examined Vygotsky’s (1978) description of play for more evidence. Vygotsky (1978) describes the nature of play with connections to symbols and creativity. He notes that children in play are a head taller because play provides the scaffold of the more capable peer in the zone of proximal development. He also connects the imagination to fantasy. While these aspects of play were present, Vygotsky’s view of play seemed too narrow for the essence of the students’ descriptions. So, to provide a broader analysis of play then Vygotsky and a more narrow analysis of play than Salen and Zimmerman, I examined the work of Donald Winnicott (2007). As a psychoanalyst, Winnicott was concerned with the origination and development of play. He began his study of play with the relationship between the infant and the mother. Winnicott situates play in a special place that is not “me”, nor is it object or “not-me”. Instead, play occupies a third space that Winnicott (2007) calls potential space. Indeed, Salen and Zimmerman’s description of play that takes place in a “space of possibility” mirrors Winnicott’s (2007) description of play as potential space. It is in this potential space that children feel more capable than they actually are, similar to the way learners feel in Vygotsky’s (1978) zone of proximal development.

Additionally, this potential space is filled with fantasy and illusion, which is similar to Vygotsky (1978). Although Vygotsky does not connect play to fantasy and illusion as strongly as Winnicott does (Libowitz, 1993). Winnicott actually moves beyond fantasy and illusion and includes omnipotence in his descriptions of play. Tuber (2008) describes the child’s beginning of this feeling of omnipotence, “Importantly, as the baby develops a sense of physical causation, there is a shift from ‘Mommy appears and it’s a miracle,’ to ‘Mommy appears and it’s my
miracle, I’m creating this miracle.’ Now if the baby has experienced that control, that beginning
capacity to feel life as play, it’s wonderfully exciting” (p. 120). Winnicott’s stronger connection
to fantasy, illusion and omnipotence is an important distinction, especially when technology is
involved, because of the virtual worlds that children experience daily while using technology.
For example, Elizabeth noted that “it’s like your own little world so it’s another world so if you
mess up on one world you can create a whole new one and it will be perfect and stuff.” Also,
Thomas noted that “…you can actually say what you want to say with technology. I like being
able to put your own opinion in there, your own thoughts, and I love seeing it come out. Because
it looks just so much nicer digital -- everything looks nicer digital for some reason. Everything.”
Thomas’s remarks allude to something very magical about technology. In fact, Becky called
technology “a wonder machine” and noted that “everybody wishes to have it.” She added,
“…virtual stuff, you know, it's a kids’ imagination” which most directly connects the technology
with the fantasy, illusion and omnipotence that characterize Winnicott’s (2007) potential space.
Thus, Winnicott’s potential space or play seem to directly align with the students’ views about
technology and play, but importantly, the teacher is not responsible for the fantasy and illusion
that accompany play. The students can find their own way into play using the technology.
Indeed, technology, with its strong connection to fantasy and illusion, appear to be a perfect
transitional object to move learners into a playful state.

The transitional object is the object that represents the first separation in the infant’s mind
between the infant himself and the mother and it is directly related to the development of
potential space and thus the capacity to play (Winnicott, 2007). The first transitional object might
be a security blanket or a plush stuffed animal. As children develop, more and more objects hold
the transitional quality and children’s capacity to play broadens and deepens. Play broadens to
the extent that Winnicott (2007) likens play in children to concentration adolescents and adults, thus needing no object at all. However, while not necessary, transitional objects can be used for children to move into the potential space of play. Transitional objects lie between subjective and objective. “It comes from without from our point of view, but not so from the point of view of the baby. Neither does it come from within” (Winnicott, 2007; p. 7). Students noted this type of paradox. For example, Thomas discussed how important it is to personalize his technology. Indeed many students attempt to personalize the wallpaper of the school’s computers even though they know that when the system restarts, their personalization disappears. Specifically, Thomas said,

Where kids are like ‘oh I wonder how I can customize my thing.’ Like if you could see my cell phone it is completely opposite of how I originally got it because I like, every time there is something I can personalize, I’m like ‘oh I better personalize this and this and this and this.’ I like personalizing my stuff. So I think that’s probably with most kids. I mean in here, who likes personalizing your stuff? Pretty much everybody. So, where adults… I don’t think they care as much about personalizing their stuff as kids do.

As children are “personalizing,” they are blurring the lines between the “me” and the “not-me” ultimately creating the paradox of the transitional object and further fueling the fantasy and illusion of play. Grandy and Tuber (2009) used children’s literature to identify several transitional objects, including the wardrobe in C.S. Lewis’ (1950) *The Lion, the Witch, and the Wardrobe*, the rabbit hole in Carroll’s (1865/1951) *Alice in Wonderland*, and the tollbooth in Norton Juster’s (1961) *The Phantom Tollbooth*. In these stories, the transitional object is a portal into imaginary space or potential space. The authors evaluate that threshold or transition as a “signal of the way in which the protagonist experiences and occupies their particular imaginary
space” (p. 275). In other words, Alice’s experiences after a frightening free fall down a rabbit hole are considerably different from the children’s experiences in Narnia after willingly exploring the wardrobe and Milo’s experiences to find meaning after he constructs his own tollbooth. In viewing the transitional object as a way to foreshadow the quality of the potential space, the use of technology as a portal to play is especially powerful to connect with important learning. Indeed, technology is a transitional object that brings students to the being playful category of play as described by Salen and Zimmerman (2004), then the particular work or virtual manipulative can bring students into the ludic activity category of play, allowing students the opportunity to play with the structures of mathematics. Importantly, because of the enormously positive emotional connections students have with technology, the use of technology as a transitional object provides a means to make play meaningful and indeed make school meaningful. Specifically, students describe technology as “fun”, as a place they want to explore and as a place they enjoy making their own through personalization. These traits of the transitional object are all also traits of powerful learning. These were also the traits which were clearly demonstrated through students’ work during this study, work which was completed as students engaged in the potential space of digital play.

Play has been documented as an important construct for learning even with adult students (Dondlinger, 2009; Warren, Dondlinger, & McLeod, 2008). In these studies, students communicated a willingness to play and explore as they learned in an alternate reality game setting, similar to the students in this study but without the alternate reality game. Certainly, exploration is a key component of play. It is also a key component of curiosity. Further both play and curiosity have strong connections to persistence. Thus, curiosity and play will co-exist often and educators interested in fostering curiosity can and should also foster playfulness.
Welcome versus Unwelcome Scaffolds

This theme presented itself from the very first interview. During that interview, students discussed the resizing images work and the Thinking Blocks manipulative. Students’ reactions to these two pieces of work were drastically different. The resizing images work was viewed very positively and the Thinking Blocks manipulative was viewed rather negatively. For example, with the resizing images work, Elizabeth noted that she liked the “resizing the images better… because instead of just having to work it out on paper with everything written out, you can kind of understand it but when you actually see it you really know what you are doing.” This positive view of the resizing images work was coded as *technology scaffold* and was also echoed by other students. Indeed, no student offered negative feedback about this manipulative. On the other hand, the Thinking Blocks manipulative garnered mixed reviews. Some of the scaffolds offered by the Thinking Blocks manipulative were appreciated. For example, Becky appreciated the algebra button on the manipulative that allows students to see the formal algebra that can be used to solve the problem they just solved without the algebra. She said, “I’ve been following along with the steps and then at the end I press the algebra button to see all the algebra I’ve done.” Other students appreciated the hint button that the manipulative offered. However, Thinking Blocks also had negative feedback which was coded as *technology impediment*. Marissa described her Thinking Blocks work saying, “It was a lot. It was very frustrating. You had to put a lot of time and work and energy and your brain and well sometimes like if you knew the steps matter so if you just didn’t do one thing right it would just mess everything up for you. Your mind got scattered. Then we tried to solve the problem and drag the boxes to the little rectangles… it was kind of too much. All this stuff and it just made me very angry.” These
opposing views of the two pieces of work made me question the underlying reason for the different views.

The next weekly interview offered an opportunity for students to discuss three additional virtual manipulatives that each offered scaffolds: percent grid; decimal to percent; and fraction to percent. During this second interview, all three of these manipulatives received positive feedback. Only one instance was coded as *technology impediment* during this week two interview. In this instance, Karen was discussing the fraction to percent manipulative. This manipulative was actually designed just for fractions. The manipulative offers the first fraction and the students build an equivalent fraction. For this work, I simply asked students to build the ten by ten grid for the percent model on the second fraction. Then, they would shade that percent grid they created until it was equivalent to the fraction. However, if the fraction provided by the manipulative had a denominator that was not divisible by 100, the students could not model an exact equivalent match. Karen discussed her frustration with this problem, saying, “if it wasn’t equal, I didn’t do the check button because it can be aggravating. I don’t know if it was the website that we used always or it was…” All other technology based codes for week two were positive.

By examining both weekly interviews and evaluating the manipulatives used during both weeks, the scaffolds used for the Thinking Blocks manipulative were different from those used by any of the other manipulatives. Sharma and Hannafin (2007) reviewed the literature for technology based scaffolding and noted two types of technology based scaffolds: cognitive and interface. The cognitive scaffolds will scaffold a process with supports for the steps involved while the interface scaffolds focus on communicating representations. Indeed, this was also the difference between Thinking Blocks and all the other manipulatives. The Thinking Blocks
manipulative was the only one which would be considered a cognitive or procedural scaffold. The other scaffolds were all interface or representational scaffolds.

Certainly, scaffolds were not originally conceived as permanent structures. Indeed, scaffolds provide structure and guidance to novices while performing within the zone of proximal development, but this guidance is only offered as long as the novice needs assistance. The ultimate goal of course is that the learner can perform the task without assistance from the expert or without the use of the scaffolds (Vygotsky, 1978). Consider the metaphor of a scaffold as a step stool that a child might use in order to reach and use the sink to wash hands or brush teeth. It is inconceivable that the step stool would be a permanent structure because as soon as the child develops and grows enough to reach the sink without the step stool, the child will most certainly want the stool removed. However, some technology based scaffolds were permanent structures within the digital learning framework, a common issue for designers (Sharma & Hannafin, 2007). These were the structures that frustrated students and were coded as technology impediments. The Thinking Blocks modeling of proportions was particularly troubling to students. First, students noticed that the screen was filled with information that was difficult to assimilate and use. Sarah said,

What I thought was unexpected was that all the stuff that was on the Thinking Blocks.

There was the read the problem, your math teacher says, problem solving steps and build your model. I feel like there should only be like 2 or 3 of those instead of just all of them because with the read the problem they had the problem, the build your model was you had to build it and then you had to put a question mark and then do all these numbers which was really confusing then you had to read what the math teacher said at the same time and
then the problem solving steps which both are pretty much the same thing so I just got really confused with so much.

All of the information on the screen is designed to assist the student through the problem solving process, but the sheer volume of information made the process feel overwhelming. Other students did not appreciate the built in scaffolds that could not be eliminated. John said, “For me what was unexpected, whenever it said build your model on the Thinking Blocks, it asks you to put the question mark no matter what… you don’t need a question mark. You already know the answer so it was really annoying. I don’t want to put a question mark.” This question mark was meant to denote the unknown value that the students were working to solve, but to the students, the question mark only seemed to communicate the sense that they were incapable of finding the answer without being led in a lock step fashion. In another example, Marissa noted, “The thing that was very unexpected was… when we were done with the whole entire problem and we already had the answer in there, the little box would pop up and say you need to put it in there again. It was kind of like pointless to have to just do it again and that really got me off and that was the part I didn’t really like about it.” In this situation, the manipulative asked students to use the model to work out the problem. Once students found the answer, they were asked to input the answer again as a response to the original problem that was provided, which felt repetitive to students. All of these impediments combined to bring a level of frustration to students’ problem solving that actually interfered with the mathematics that it was designed to scaffold.

In contrast, some manipulatives offered scaffolds that students truly appreciated. Even the Thinking Blocks had redeemable scaffolds, including a hint button that several students noted and appreciated. However, the majority of scaffolds that students acknowledged as helpful were actually scaffolds that illuminated the underlying mathematical concepts, which Sharma and
Hannafin (2007) call interface scaffolds. For example, the *material intelligence* code and the *visual model* code both provided scaffolds that allowed students to explore the limits of the mathematical concept and provided important mathematical feedback to students along the way. Other scaffolds imbedded into the environment did not necessarily provide mathematical feedback, but offered students clues as to options to proceed or to solve such as the up arrow button on the percent grid manipulative or the multiplier button on the resizing images work. Finally, some scaffolds amplified students’ efforts such as those coded with the *amplification of effort* code. This scaffold, particularly seen during the resizing images work and the percent grid work, allowed students to explore purposefully and to use their cognitive energy for other learning activities.

These two ends of the scaffolding spectrum demonstrate students’ sensitivity to the amount of guidance or assistance they need in order to learn. Clearly, students in this study would rather be in a position of exploration where they are looking for and evaluating the concept under study rather than in a position to be led through to the solution to a problem. In this way, it is easy to see how some scaffolds are welcomed by students while other scaffolds are unwelcome. Ultimately, designing technology-rich learning to include as many scaffolds as necessary to aid in students’ understanding while also not inhibiting their learning is a challenge that must be more universally met. While Sharma and Hannafin (2007) found that learners many times lack the ability to select and use appropriate and helpful scaffolds, this study disputes that finding as the students understood exactly which scaffolds were helping them and which ones were frustrating them.

This theme of scaffolding has strong implications for curiosity as the interface scaffolds allow for more opportunities for the freedom of exploration necessary to foster curiosity than do
the cognitive scaffolds. In other words, when educators are interested in fostering curiosity but know that learners need scaffolding for their learning, they should opt for interface scaffolds rather than cognitive scaffolds. Cognitive scaffolds can be offered by the teacher so that he or she can naturally fade the cognitive scaffold when it is no longer necessary for the learner.

*Action is Power; Power follows Ideas*

Students’ reactions to the different work during the study varied widely, from *fun* and *easy* to *frustrating* and *confusing*. However, the reactions that stemmed directly from the technologies used ranged from *addicting* to *disappointment with technology*. These reactions to the technology are at the heart of the final theme, *action is power; power follows ideas*.

This theme was the last one to emerge from the data. The theme began with the strong presence of the prosumer stance (Tapscott & Williams, 2006) present during the procedural knowledge interview and documented in the *seeing possibilities* code. A prosumer is a consumer who improves, changes or adapts existing works or products to incorporate his/her own tastes. The code of *seeing possibilities* captured this stance when students were expressing their disappointment with technology. Thomas discussed the Study Buddy™ device and his disappointment in it, saying,

Well, Study Buddies™, I enjoyed them but I also don't at the same time. It would be nice if they were interactive and not just a digital textbook… It doesn't do anything fun, it's just answer questions. It mean, it would be more fun if it was a kind of video-game style. It would have a certain thing and ask you a problem based on the problem and information instead of one, two, three, four, and a, b, c, d and blah, blah. That, it's not exactly fun.
Crucial to the *seeing possibilities* code though is that students did not merely complain about the device or just stop doing the work using the device. They actually engaged in the harder work of looking for ways to improve the device and thus the work. In this situation, students agreed that the device should strive to be similar to some of the virtual manipulatives and games we use during class because “it's not all game, it's not all work. It's right in the middle. Where it's fun and interactive. But it's also structured and homework at the same time.” I wondered why students would engage in this prosumer stance when clearly the easier path was to do nothing. But ultimately, students indicated that their *disappointment with technology* stemmed from the fact that it did not allow them to do anything. Marissa described her disappointment with the device, saying, “it is because there is not a lot of stuff to do on it but to answer questions. They [students] would be more interested in it if it did something else.” In other words, while it might be easier to do nothing, students actually indicated they desired the capacity to act and their disappointment stemmed directly from any restriction on their capacity to act. This *seeing possibilities* code was students’ indicating their desire to act. Indeed, power is the capacity for action in society (Barnes, 1988).

Akin to mechanical power as the capacity for work, social power is the capacity of individuals, groups or organizations for action in society. While action itself does not necessarily equate to curiosity, the exploration of curiosity cannot happen without the capacity to act. Conversely, when action is restricted to responding to questions, the exploration of curiosity is impossible.

Thus, as I explored power more deeply, I was looking for ways in which the types of power either expanded or contracted the capacity for action. The nature of power dynamics and its implications and importance for twenty-first century classrooms has been explored in depth.
(McLeod, Lin & Vasinda, in press). From their analysis, eight sources of power were identified as were four outcomes of power attempts (See Table 25 which lists and defines the eight sources of power along with Table 26 which lists and defines the four outcomes of power attempts. See also McLeod, Lin & Vasinda, in press for a more detailed analysis.)

Legitimate, referent, reward and coercive powers are prevalent and dominant in our old and current classroom structures. They present a top-down structure of an educational system that uses external forces or incentives to push students to learn. These powers may work sometimes, but too often they do not. Importantly, it is also these powers that work to limit students’ actions in the classroom and thus stifle curiosity.

Expert power, information power, ecological power and power over oneself reside in children’s daily experiences outside the classroom and are particularly relevant in our twenty-first century classrooms. It is in these four types of power that the differences in the technology used in the study can be seen. In general during this study, the more the technology restricted the students’ capacity for action, the more students were disappointed or dissatisfied with the technology. Because the definition of power is the capacity to act and because students’ curious explorations require a capacity to act, this restriction on students’ action is a worthy analysis. This was particularly evident with the Thinking Blocks work and the Study Buddy™ technology. With the Thinking Blocks and its cognitive scaffolds (Sharma & Hannafin, 2007), students did not like being led through every step over and over again. As Olivia said, going step by step, it drags, you know, doing it over and over and over and over. Doing the same step again and again and again.” This was a desire to exert their ecological power, or control over their environment. Indeed it was the opposite, the Thinking Blocks website exerted ecological power because it controlled or restricted the capacity to act, which is the definition of power. They also did not
<table>
<thead>
<tr>
<th>Source of power</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legitimate power</td>
<td>An agent has formal or cultural authority over a target.</td>
<td>Adult-child relationships in schools are governed by cultural norms that allow teachers to have legitimate power.</td>
</tr>
<tr>
<td>Referent power</td>
<td>The target seeks the approval of the agent or has strong feelings of loyalty or admiration</td>
<td>The agent can influence the target because the target seeks to please the agent. For example, when students struggle to be accepted by their teachers or peers, referent power is at work.</td>
</tr>
<tr>
<td>Reward power</td>
<td>An agent’s ability to use rewards to influence the target and gain compliance</td>
<td>Compliance is not guaranteed with reward power as the target will continuously evaluate the probability of receiving the reward and whether the reward is worth the agent’s compliance. Many teachers use reward power in the classroom for students who follow the classroom rules.</td>
</tr>
<tr>
<td>Coercive power</td>
<td>Uses threats or punishments for noncompliance and is typically considered an opposite to reward power</td>
<td>Traditional teachers use coercive power when they take away a privilege or threaten a failing grade.</td>
</tr>
<tr>
<td>Expert power</td>
<td>An agent has specific knowledge or skills, particularly unique knowledge and skills</td>
<td>Many times, a target wants advice from another and thus can be influenced via expert power. Teachers traditionally are viewed as having expert power. In twenty-first century classrooms, expert power can also come from students.</td>
</tr>
<tr>
<td>Information power</td>
<td>The control over information</td>
<td>In schools, administrators hold information power. Teachers can also hold information power over students.</td>
</tr>
<tr>
<td>Ecological power</td>
<td>Control over the physical environment or technology</td>
<td>Teachers have power over the physical layout of a classroom. Technology lab managers in a school might control teachers’ and students’ access to the computer lab.</td>
</tr>
<tr>
<td>Power over oneself</td>
<td>Power which one exerts over oneself</td>
<td>It is that internal locus of control. In a classroom, ultimately it is students who choose whether they learn a particular lesson. Schlechty (2002) believes students should be viewed as volunteers in the classroom even when their attendance is compulsory. By doing so, teachers recognize that even when students are present, they must choose to engage and learn.</td>
</tr>
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</table>
Table 26

*Outcomes of Power Attempts and Definitions*

<table>
<thead>
<tr>
<th>Outcome of power</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commitment</td>
<td>The target accepting the power attempt and internalizing a change in behavior, which can be long lasting. Commitment typically results from referent or expert power.</td>
</tr>
<tr>
<td>Compliance</td>
<td>A situation in which the target performs as requested but with minimal effort and no internalized change.</td>
</tr>
<tr>
<td>Resistance</td>
<td>The target actively avoids and sometimes even sabotages the power attempt</td>
</tr>
<tr>
<td>Liberation</td>
<td>Oppressed people liberate themselves through education. Liberation is viewed as a jointly negotiated reality between the agent and the target. Ideally in school settings, teachers hope to see commitment and liberation in their student’s learning and try their best to prevent students from resisting or reluctantly complying to what’s been taught at schools.</td>
</tr>
</tbody>
</table>

like several of the scaffolds such as the question mark. Requiring the question mark was certainly a way in which the site was exerting ecological power, but this cognitive scaffold (Sharma & Hannafin, 2007) was also an assault on students’ expert power. In other words, John noted that he could not understand why he had to use the question mark because he already knew the answer. It appeared to the students that the Thinking Blocks designers did not believe that the students were capable of proportional thinking without aids such as the question mark.

With the Study Buddy™ device, students again expressed disappointment with their inability to act. Thomas noted that he wished you could do something else besides just answer questions. He said, It doesn't do anything fun, it's just answer questions.” In other words, the device restricted students’ ecological power by defining the way students could act while using the device. The device also restricted students’ expert power as it assessed correct or incorrect responses to the questions. Of course, students who were sensitive to expert power subverted the device by just memorizing the correct answer.
With both examples, students also noted less power over oneself. Ultimately, students must choose to engage in the hard work of learning. The self-regulatory behaviors category demonstrated many examples of ways during the course of the study in which students would support themselves during their learning. However, recall that the self-regulatory behaviors were lower during the procedural knowledge work, including one negative code of lack of purpose or organization. Additionally, the discovery and learning category was the lowest during the procedural knowledge work, indicating that students might not have felt the capacity for power over themselves.

In contrast, during work such as the percent grid and resizing images, students expressed their ecological power as they described their explorations, their trial and error, and their invented play. For example, Jacob discussed his exploration and playfulness by saying that he liked “the percent grid because whenever we went to explore we could just mess around with it.” During work such as mathcasts and Math Out Loud, students noted their information power and expert power as they created information that others could access with codes such as critical and evaluative thinking and wide audience. For example, Marissa discussed the research for her Math Out Loud word story saying “the etymology was kind of interesting because you wanted to learn more about the word and its history.” During work such as virtual sorting during Folders of Wisdom and Knowledge, students noted their power over themselves with codes such as accepting ownership and distinguishing differences. For example, Jacob noted, “I know that… whatever I do and if I actually like study this and actually know it, I can get farther in life.” In general, students indicated with the it’s virtual code that they desire the capacity to act through exploration and personalization. For example, Elizabeth personalized her own learning during the decimal to percent work. She described it by saying, “Whenever I had a number it was way
too easy. It was just like zero and nine hundredths. It was kind of boring because I just kept on getting really easy ones so I was, I would go to the next problem and if was a hard one then I would do it.” When those actions are restricted, students’ learning and desire for learning appeared to be diminished as does students’ curiosity.

Warren, Dondlinger and McLeod (2008) noted that students perceived their power to act when they had gained sufficient knowledge. Indeed, an important connection for curiosity is also knowledge as the definition of curiosity surrounds creating, maintaining or resolving gaps in knowledge. This connection to knowledge supports the second part of this theme *Action is power; power follows ideas*. Bennis (2003) contends that power now follows ideas rather than position. Thus, educators are no longer in a position to expect students to follow simply because they are ‘the adult’ or ‘the teacher’. Ultimately, power now follows ideas, and in the case of this study, power follows mathematical ideas. For example, during their Math Out Loud work, students spent some time initially researching their word and brainstorming a hook. When all aspects of the script were prepared, students would collaboratively write the script. John described the script writing process by saying, “Something unexpected I had was writing the script was actually the easiest part… the script was discovering itself. It was like building itself. It was writing itself.” These words were coded as *flow* as they capture students’ description of a state of flow similar to Csikszentmihalyi’s (1997) definition. Specifically, *flow* describes times when the task’s level of challenge is appropriate for the learner’s skill level. There is just enough challenge to make the task interesting but not so much challenge that the student believes he or she cannot complete the task. John’s description of the script writing itself indeed equipped John with the capacity to act in scriptwriting because of the knowledge he had gained during the research phase of the work. In another example, the class had just listened to another block’s
Math Out Loud word story recording. Jacob was disappointed that the group did not yell “Math Out Loud” at the end as is tradition with the word stories. He said, “This place is all about expressing math, not keeping it quiet.” Jacob’s words indicate that students’ capacity to act during the Math Out Loud recording stem directly from their knowledge of the math vocabulary. Thus, overall, when students connect their capacity to act with their knowledge, they are experiencing the second part of this theme, power follows ideas. They are also demonstrating the reciprocal nature of curiosity. In other words, when students learn something, they could be either satisfying their curiosity or perhaps exposing a gap in their knowledge, both of which are integral to curiosity.

Summary

Researchers transcribed and coded the interviews, identifying 60 codes and four categories. The categories were self-regulatory behaviors, discovery and learning, digital tools and emotional connections to learning. After analyzing the data from the research questions, the data were turned to evaluate across knowledge work. Finally, three themes emerged from the data. The themes were digital play, welcome versus unwelcome scaffolds and action is power; power follows ideas.
CHAPTER 5
CONCLUSIONS AND IMPLICATIONS

Introduction

After examining the codes, categories and themes of the study, it is now time to turn attention to the conclusions and implications. First, each theme is addressed individually for its conclusions and implications. Then, the study in general is analyzed. Finally, the chapter ends with future directions for continued research.

Conclusions and Implications by Theme

Play has an important connection to curiosity as the digital play theme identified in this study and curiosity is important to educators. Thus, play has a vital place in scholarly work surrounding learning. Indeed, when Vygotsky (1978) studied children at play, he described its importance by saying that children are a head taller at play. He found that play stretched a child’s development beyond the child’s actual developmental age and considered play to be the more capable peer in the zone of proximal development. Further, when speaking with experts in a field, they are much more likely to talk about playing with an idea or getting to know an idea rather than testing themselves rigorously over a topic (Papert, 1993a, 1993b). Finally, Winnicott’s (2005) potential space is noted as a “breeding ground for creativity, mastery and aliveness” (Tuber, 2008; p. 125), adding to the scholars who connect play with achievement and mastery. Of course, this connection to achievement and mastery is critical in today’s standards based, high-stakes testing environment where the only measure of learning that is politically valued is standardized test scores.
Papert (2002) understands that children at play do not shy away from challenges. In fact, he coined the term “hard fun” to describe when children consider playing fun because it is hard and challenging. In other words, children do not necessarily want fun or play that is trite as it could belittle their intellect and their sense of adventure. Thus, play does not have to equate to whimsy, but can be serious, challenging and motivating as demonstrated in this study. Students capitalized on their curiosity and used all of Salen and Zimmerman’s (2004) categories of play in ways that pushed their learning to new levels.

Winnicott (2005) also juxtaposed study and play. In his scenario, he described a situation in which people had a place for study but not for play. He admonished this situation, calling it a “poverty of play” (p. 147). Winnicott (2005) concluded that all who care for children must help children experience the potential space because it leads to creative living and scientific discovery.

Salen and Zimmerman (2004) offer a way in which play can be used which could even benefit an unyielding environment like the standards based, high-stakes testing environment. Called transformative play, it is a “special case of play that occurs when the free movement of play alters the more rigid structure in which it takes shape” (Salen & Zimmerman, 2004; p. 305). In other words, the implication is that transformative play can alter the rigid and formal structure of school into more fluid, natural learning, more similar to the type of creative living and scientific discovery that Winnicott (2005) describes in his potential space. While this may seem unlikely, Salen and Zimmerman contend that “every instance of play carries with it the seeds of transformative play” (p. 306). In other words, anytime play is happening, it could become transformative play. Indeed, it seems more plausible when considering the quality of technology as a transitional object ushering students into a playful stance. In this study, technology was
credited with fun, exploration and personalization, all of which are important for learning and play. When technology is used in schools as envisioned by the State Educational Technology Directors’ report, *Class of 2020: An Action Plan for Education* (2008), and students use technology as a high quality transitional object to move into a playful state, formal school learning cannot remain stagnant.

Scaffolds are an important part of the learning process, but with the welcome versus unwelcome scaffolds theme, it is possible to see the negative side of scaffolding. Humans naturally and dynamically offer and withdraw scaffolds to assist learners at the proper time. But many times, technology such as the virtual manipulatives used in this study are programmed to work in a particular manner without any intelligence built in to adapt to learner proficiencies. Certainly when scaffolds are used judiciously, whether digital scaffolds or human scaffolds, the effects are that learners feel competent with just the right amount of challenge. These feelings can be noted in the feelings of competency and addicting codes and also with technology scaffolds such as material intelligence, visual model, and amplification of effort. These codes signify learning principles that are present in the most compelling commercial video games (Gee, 2003). Importantly then, this study has demonstrated that it is possible to create learning environments with many similar learning attributes of commercial video games, but without the expertise or expense of designing and creating a commercial quality video game.

While well placed and mathematically based scaffolds were positively viewed by the students in this study, other scaffolds earned mixed or negative reviews. The scaffolds in the Thinking Blocks might have been helpful for the first few questions, but students quickly became disenchanted with them, making them a distraction, even an impediment to learning. However, not all students are ready to give up a scaffold at the exact same time. Thus, the ability
to personalize the scaffolds that are not mathematically based could be an important progression for designers. In other words, just as one personalizes a mobile phone to only show certain features while other features are hidden, students should have the opportunity to personalize their workspace so that scaffolds can be turned on or off as needed during learning. This personalization could be a powerful one that not only allows students to explore, discover and appreciate the value of the scaffold, but also one that taps into the digital play theme and the action is power; power follows ideas themes. It would also put students back in a position of exploration as they identify and adjust their desired level of scaffolding. Moving students into the exploration role encourages curiosity instigated learning.

Many of the technologies used honored students’ power to explore on their own terms while providing mathematical feedback that assisted in their learning or while providing a venue for students to “put [their] own opinion in there, [their] own thoughts” because “[they] love seeing it come out.” This is at the heart of the action is power; power follows ideas theme. Indeed, another of Gee’s (2003) principles is the discovery principle which states that “overt telling is kept to a well-thought-out minimum, allowing ample opportunity for the learner to experiment and make discoveries” (p. 211). While discovery learning is powerful and motivating (Bruner, 1966), it is challenging in a standards based environment because teachers have no guarantees that students’ discoveries will correlate with the standards. When those standards are backed by high stakes tests, discovery learning is many times abandoned. In this study, students’ discoveries aligned with the standards because the work was designed to channel the exploration and discovery into the mathematical thinking of the ratio and proportion standards. These discoveries were then followed by reflections, typically in blog postings, because reflection and
metacognitive thinking has been shown to aid in transfer of knowledge (Bransford, Brown & Cocking, 2000).

Of course, some restriction of action, or restriction of power, was acceptable to students. For example, students did not mind the mathematically based scaffolds during the conceptual knowledge work or the assessment of concept during the virtual sorting of the Folders of Wisdom and Knowledge during the problem solving knowledge work. Indeed, these restrictions were necessary in order to ensure that students learned the concepts that the state expects. While necessary, it is difficult to maintain those restrictions without the benefit of the digital tools. This paradox of exploring using the technology but also finding limits to the exploration mirrors Salen and Zimmerman’s (2004) paradox of play and Winnicott’s (2005) paradox of potential space. In play and in potential space, a paradox exists in which children push limits and appreciate boundaries. While students want their power recognized and honored, they will also acquiesce to a system of play rules. These rules can be for the benefit of the play similar to the rules of games or the rules can be the rules of mathematics. Either way, this paradox allows educators to channel discoveries while honoring children’s ecological, information, expert and power over oneself.

When these powers are honored, children experience school learning in a way that is congruent with their out of school learning. It is also an environment conducive to curiosity as students are free to explore the limits of the mathematical concept in the way that is most helpful for them. Students respond to this alignment of school and out of school learning with deep commitment, one of the important outcomes of power attempts. Further, the transformative play allows both the students and the teacher to discern a new reality, demonstrating the liberation outcome of power attempts. These two power outcomes stem from and generate the self-regulatory behaviors noted in this study. Importantly, it is learning born from curiosity that
generated the self-regulatory behaviors and the environments for students to exercise their power congruent with their out of school learning.

Overarching Conclusions and Implications

Recall that curiosity held five important aspects of relevance to educators: 1) curiosity’s connection to knowledge and higher order thinking; 2) curiosity’s connection to motivation and persistence; 3) curiosity’s connection with goal oriented behavior; 4) curiosity’s reciprocal nature; and 5) curiosity’s antitheses of boredom and anxiety. Of these five, the first three were specifically found in this study. The self-regulatory behaviors category aligns with curiosity’s connection with goal oriented behavior and with persistence. The discovery and learning category aligns with curiosity’s connection to knowledge and higher order thinking. The emotional connections to learning category aligns to curiosity’s connection to motivation. Thus, this study’s context maintained all of the positive aspects of curiosity that are crucial to educators. It also introduced something new and qualitatively different, namely the digital tools category. In previous studies, technology has been purposefully matched with research based strategies to maintain the integrity of the strategy while the technology brought additional benefits (see McLeod & Vasinda, 2009; Vasinda & McLeod, in press b). Specifically, the digital play theme illuminated important ways in which technology brought students into a playful stance and even created an environment for ludic play with mathematical concepts. The welcome versus unwelcome scaffolds theme offered insights into the types of technology based scaffolds that fostered students’ curiosity and the types of scaffolds that stifled students’ curiosity. Finally, the action is power; power follows ideas theme assists educators in envisioning a new classroom power dynamic that more closely resembles the curiosity based, discovery learning that is
common outside of the classroom. Postman (1992) notes that technology offers a Faustian bargain in all situations. In other words, technology always provides something important but also takes something away. For example, the online world of shopping, banking and more offers many conveniences but also takes away important face-to-face personal interactions. This study introduced a possible exception to Postman's Faustian bargain. Using technology-rich learning brought all the research based benefits of curiosity into the sixth grade mathematics classroom and did not take away any of those important benefits. Importantly, technology also added something important to the students’ learning. This exception is possible because of the careful matching of proven strategy with technology (McLeod & Vasinda, 2009), matching that should continue to be explored, researched and documented.

Another important implication is that this curiosity fostering, technology-rich learning occurred in a standards based, high stakes testing, Title I school environment. These environments are not known to spark curiosity. In fact, the opposite is typically true. Standards force a particular curriculum that cannot waiver depending on students’ interests and desires. The high stakes testing introduces anxiety into the learning environment which counteracts curiosity. These two factors combine with the many negative learning implications of students from poverty in Title I schools to create an environment that is not conducive to curiosity. Thus, the fact that curiosity and learning thrived in this environment is of major significance to educators. It means that even standards, testing and poverty are not death sentences for curiosity when technology is purposefully matched and integrated.

Finally of overarching importance is the idea of balance that permeated this study. In many situations, the teacher and the students balance competing and opposing ideas or concepts in order to maintain a curiosity friendly learning environment. For example, the fun versus
learning code captured students’ desire to balance the fun they would like to have while learning with the hard work of homework that is their reality. Interestingly, during the conceptual knowledge work, students strongly connected fun and learning, indicating that they persevered because it was fun and learning together! But during the procedural knowledge work, students felt that fun and homework based learning might be opposed to each other and require some balancing act. In another example, the technology scaffold and technology impediment codes illuminate a balancing act in the amount of assistance offered to the learner. The intrusiveness of the technology scaffolds that were used required balanced in order to be conducive to curiosity. The more intrusive a scaffold was, the more quickly students became frustrated with the scaffold. On the other hand, scaffolds that were almost invisible, that merely served as the mathematical structure, allowed students to have significant exploratory freedoms and fostered curiosity. Some concepts are certainly more difficult for some students. Also, as students learn more abstract and challenging mathematical concepts, the likelihood that quality manipulatives are available that offer the types of scaffolds found during this study. Thus, designers will need to learn the balance of scaffolding students’ thinking so that they provide enough support to decrease frustration and anxiety but enough freedom for students to explore the mathematical concept. A final balancing example came from the addicting code. Certainly, addiction can result from both intrinsic and extrinsic forces. In this study, students cited both sources for their addiction. For example, the intrinsic addiction resulted from feelings of competency and fun codes that students used alongside the addicting code. In other words, the technology-rich learning helped the students feel competent and was fun. Thus, they did not want to stop the work even when they had to stop. Addiction can also stem from extrinsic forces. In this situation, the technology might offer some external reward such as a ribbon or a raise in rank. While this was not specifically
noted in this study, these external rewards are a part of some of the technology used during the course of the year in sixth grade mathematics. Certainly with this example of balancing intrinsic and extrinsic sources of addiction to the learning, any bias should always fall on the intrinsic side. The external rewards can also bring some aspects of play into the hard work of learning, but in the end it is important that students find that learning offers its own reward. Thus, educators must balance these external rewards and grapple with when it is appropriate to fade those sources and allow for the intrinsic forces of addicting learning to take root.

Directions for Future Research

Future research in the area curiosity and technology has many venues. Recall that curiosity research with technology-rich learning was not found during the literature search. Thus, significantly more research is necessary to make definitive statements. For example, this same research design should be repeated with other grade levels and other subject areas to compare results. Of course, these new studies should include different technologies as well to comparatively evaluate the impact of the differences on students’ curiosity. Also, future studies should include larger samples with different methodologies, including quantitative methods. All of these means of studying curiosity in a technology-rich learning environment will either offer the findings from this study more evidence or perhaps bring to light additional important findings that were not evident with these participants.

Another line of research could include the teacher’s actions in a technology-rich learning environment and the implications of those actions. Beyond the work planned for students, some teacher actions likely foster curiosity while other teacher actions likely stifle curiosity. Teachers must understand how their actions help or hinder learning. Those actions and their implications
could be very different in a technology saturated classroom. Thus, while not the purpose of this study, a worthy line of inquiry would examine teacher actions and evaluate how those actions affect curiosity and learning. The inquiry would also examine how teacher actions differ in technology-rich learning and in traditional classrooms.

Finally, each of the identified themes in this study is worthy of separate research. Digital play should be researched to examine other implications to learning, both positive and negative, to students’ tendencies for play when using technology. Designers should study the welcome versus unwelcome scaffolds so that future technology based environments honor and respect students who need and who no longer need scaffolds for learning. Designers can also study the ways in which the learning principles from commercial video games can be leveraged even without the time and expense of the game development. Finally, power dynamics should be further evaluated to determine how the structures of school can more fully support student learning while exercising the types of power that are common to students outside the classroom.
APPENDIX A

SEMI-STRUCTURED INTERVIEW PROTOCOL
1. As you were participating in the __________ activity (insert the particular technology based work that is being studied) this week, describe a time when you were actively exploring for as much information as you could. What made you want to explore?

2. As you were participating in the __________ activity (insert the particular technology based work that is being studied) this week, was there anything unexpected that happened? How did it make you feel?

3. As you were participating in the __________ activity (insert the particular technology based work that is being studied) this week, describe a time when the work was complex or challenging. How did you feel about being challenged? How did you help yourself during the challenging time?

4. As you were participating in the __________ activity (insert the particular technology based work that is being studied) this week AND thinking about the time when you felt challenged, describe your thinking as you persisted in the work.

5. As you were participating in the __________ activity (insert the particular technology based work that is being studied) this week, describe a time when the work made you nervous. How did you feel about being nervous in class? What did you do to help yourself?

6. As you were participating in the __________ activity (insert the particular technology based work that is being studied) this week, describe a time when you learned something about yourself or the world. How did that make you feel?

7. As you were participating in the __________ activity (insert the particular technology based work that is being studied) this week, describe a time when you did more than the assignment required. Why do you think you did more than you were asked to do?

8. As you were participating in the __________ activity, think about how confident you felt in your ability to complete the work. Would you describe yourself as a lion (very confident) or a kitten (timid)? Why?
APPENDIX B

CODE REFERENCE DOCUMENT
<table>
<thead>
<tr>
<th>Code</th>
<th>Definition and Examples</th>
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</thead>
<tbody>
<tr>
<td>Accepting Ownership</td>
<td><em>Definition:</em> This code captures students’ acceptance of the ownership for the learning. Students are not trying to blame anyone or anything else for their frustrations or confusion but are trying to work through it themselves.</td>
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<tr>
<td></td>
<td><em>Example:</em> Karen “I didn't really want to ask you, because I really wanted to find it out myself.”</td>
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<tr>
<td>Access</td>
<td><em>Definition:</em> Students discuss the implications of having or not having access to technology from home.</td>
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<tr>
<td></td>
<td><em>Example:</em> Karen “Well we did… it was decimals into percent I really wanted to do more but the class was over and if I had a computer at my house I would definitely have done it.”</td>
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<tr>
<td>Addicting</td>
<td><em>Definition:</em> The students defined addicting as both good and bad. It is a behavior addiction that they describe, as opposed to an addiction to a substance. John noted that “your body believes that you need it [the behavior] or your brain thinks that you need it [the behavior].” Certainly, it is a behavior that you do not want to stop doing, which as Allison notes, is both good and bad. She said, “I think of addicting as a good and bad thing because it’s like fun to do so you don’t want to stop but the bad thing is, you don’t want to stop.”</td>
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<td>The determining factor of whether the addiction is good or bad is whether or not they see it as productive or beneficial. For example, Elizabeth explained, “I think how some of you were talking being addicted to technology would be that it’s like your own little world so it’s another world so if you mess up on one world you can create a whole new one and it will be perfect and stuff but it can really take up your life. You know in the classroom if you are addicted to like a game or something, that’s good because it’s academic and you’re learning and it’s productive.”</td>
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<td></td>
<td><em>Examples:</em> Allison “… resizing images. Because I did a lot of those and it was like really fun and I didn’t want to stop but I had to stop because you were like, ‘We are moving on to something else.’”</td>
</tr>
<tr>
<td></td>
<td>Kevin “Because it was fun, addictive and it was learning.”</td>
</tr>
<tr>
<td>Aha!</td>
<td><em>Definition:</em> Students make a discovery of importance to them, to their work or to their learning. This is different from the making connections code and the pulling together fragments into coherent knowledge structures code because this is for very general discoveries that may not have anything to do</td>
</tr>
</tbody>
</table>
with the mathematical concepts. They were just important discoveries for the student personally.

**Example:** Madison “The thing I found unexpected was decimal to percents. I had to get more grids. I accidentally held the touch pad too long and it went up to 1000 grids and I got it right on my first try! And it was like 1.03. I got it right!”

**Amplification of Effort**

*Definition:* This code comes from Gee’s learning principle Amplification of input from his book *What Video Games Have to Teach Us about Learning and Literacy.* He defines amplification of input by noting that “for a little input, learners get a lot of output.” Amplification of effort is when students feel that they must do little but still get a lot from the work.

*Examples:* Jacob “It was very easy on the first one that we did percent because all it did was say name, explore or show and it also says a number and you have to fill it in. All you had to do was click and another graph, like it said 28, click 2 tens and then 8.”

**Challenge**

*Definition:* This code is used when the students note that the work is difficult or challenging. It is not used when students respond to a question about the work being challenging as then all the answers to that question would be coded similarly. It is used when students discuss difficult or challenging work when asked about something else.

*Examples:* Sarah “The decimal to percent is easier but I liked to do the fraction to percent because sometimes I like being challenged like with the Thinking Blocks, it was like really too much so that was like a huge challenge that I didn’t like but when it is like, when it kind of challenges you, that’s what I like to do so I like the fractions to percents.”

Becky “I think I was searching for more information when we were doing decimals to percents because I was like after you told us to stop for like the last five minutes of class I still had my computer out, I was still going because I really liked doing it. I was trying to see how many more could I do and challenging myself to do more.”

Marissa “It was actually Thinking Blocks that really got me because with some of it, it was very frustrating and it kind of got me off track and I didn’t know what to do about it.”

**Compliance**

*Definition:* This code describes behavior in which the student is complying with teacher requests or social norms in the classroom. The student is not
engaging in the work for the sake of learning or for some substituted but learning related goal such as challenging yourself or playing with the concept.

Example: Kevin [in discussing why he did more than he was asked to do] “I did 7 and we were only supposed to do 6 but I forgot to record 2 so now I have one more to go.” [I asked why he did more than he was asked.] “Because I had nothing else to do and I didn’t want to get into trouble so I just kept doing my work.”

Concept labels

<table>
<thead>
<tr>
<th>Definition: This code was used when students were still struggling with the name of the mathematical concept. They might have attempted to name it but named it incorrectly or they might have used slang such as “thing” or other generic terms to describe the concept.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example: Kevin “Well, I was actively exploring when I had an angle and I assumed it was -- what is a classified angle.” [It is classifying angles.]</td>
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</tbody>
</table>

Confused

<table>
<thead>
<tr>
<th>Definition: Students described being confused by using the word confused or by describing a state of mind in which they were not sure what course of action to take.</th>
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<tbody>
<tr>
<td>Example: Elizabeth “On Wednesday when we did the percent grid, I got one I think it was like 153% or something like that… no… that’s not it! It was 953% and I didn’t really know what to do so I made my grids but then… that was the one where we had the paper. No it was the base blocks then that I had 953%. But then when I got to the paper I noticed that there was definitely not enough room for 9 grid things so I thought, well… Mrs. McLeod would have known if I… that there would be something like that… so I didn’t know if I was supposed to maybe simplify something or… I was very confused.”</td>
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</table>

Constructing Knowledge

<table>
<thead>
<tr>
<th>Definition: Students are feeling compelled to tell the story of some evolution. For example, some students tell the story of the evolution of their mastery of a concept. Other students tell the story of how they approached their work. It is the process of constructing knowledge and may not be a finished process. This code began as “at first” because many students begin their description of this process with the words at first.</th>
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<tr>
<td>Examples: Katilin “When I first did it I thought because we were supposed to do the percent to 100 and mine was 400 so I thought I had to draw four tenths but it was really 400 percent and then, so I think fraction to decimal is easier.”</td>
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</table>
Allison “When you said we were going to be working with percents because before whenever it was like Target math or something and we had to find a percent I would have trouble with that because I didn’t really get how to do percents. But since after we learned about how to figure out percents I sort of liked it because it wasn’t that complicated.”  

Marissa “Well, at first it was kind of confusing because it would give us hard ones and then along the way it was kind of fun because they gave you the steps.”

<table>
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<tr>
<th>Critical and evaluative thinking</th>
<th><strong>Definition:</strong> Students demonstrate higher order thinking. With Math Out Loud, students engaged in critical literacy or information literacy discussions when they have depth of thinking about types of literacy or types of resources. For example, students know that information must be from a reputable source to be relied upon. Or students might note that definitions can change over time. With Folders of Wisdom and Knowledge, students were making strong connections between concepts or distinguishing differences between concepts that had previously eluded them.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Example:</strong> Jacob “I figured out that nothing stays the same for ever” Sarah “Something unexpected that happened was how many --- how many angle choices there was. There was measured angles, there was classifying angles. There was a whole bunch of angles. And I would see some angles and I would click all of them. Because it was really confusing with all of them. But I figured it out.”</td>
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<tr>
<th>Disappointment with technology</th>
<th><strong>Definition:</strong> This code is used when students voiced a disappointment with the technology they used in the learning process.</th>
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<tbody>
<tr>
<td><strong>Example:</strong> Thomas “Well, study buddies, I enjoyed them but I also don't at the same time. It would be nice if they were interactive and not just a digital textbook.”</td>
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<tr>
<th>Distinguishing differences</th>
<th><strong>Definition:</strong> This code is used when students are describing differences they are now discerning between mathematical concepts.</th>
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<tr>
<td><strong>Example:</strong> Thomas “I read the thing and it says that kind of thing in it, and I look for something with that word. So like if it says something about angles and what is the measure, and I go to measuring angles. And then I realize that's not right, now I look for something that has either the word measure or angle in it. And the way I did from there I did it kind of like that.”</td>
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| Easy | **Definition:** This code is used when students say the work is easy or that they did not have to put forth much effort. Sometimes students use the word easy when they are describing work that is just the right amount of challenge. The work feels “doable” to them so they describe it as easy. |
**Examples**: Madison “I think decimal to percent is a little easier than decimal to fraction, probably because I’m used to shifting the decimal point around and I’m not used to transitioning it from a fraction to percent.”

Jacob “It was very easy on the first one that we did percent because all it did was say name, explore or show and it also says a number and you have to fill it in. All you had to do was click and another graph, like it said 128, click 2 tens and then 8.”

Matthew “All the work this week has been very simple like what John said, it was easier than last week.”

**Experiment**

*Definition*: Students might experiment with a concept to see its limits and its reactions to certain situations. Typically, students have a goal in mind, like a hypothesis, when they are experimenting. Trial and error might come before experimenting as students are trying to gain enough experience to develop a hypothesis in order to test it.

*Example*: Madison “I think it was decimals to percent… because it got into the habit to where I wanted to have 1000 grids and see if I could get in the smallest cube and get it correct on the first try. And I did it on a bunch of them and it … I think one of them was 2.01 that they had us do and that was fun.”

**Expressing math**

*Definition*: This code began with a student’s comments about expressing math. Jacob said, “This place is all about expressing math, not keeping it quiet.” This code also holds mathematical conversations made by students as they are discussing their work during the interview.

*Example*: Elizabeth “I agree with Madison about how it is easier to convert decimals into percents instead of fractions, especially with one or two digit numbers because like if you have, like if it says zero and seven tenths, no seven hundredths, all you have to put is seven percent.”

**Feelings of competency**

*Definition*: This code is used when students’ discuss their understanding of the concept. A positive feeling of competency is when students feel that they understand the concept.

*Example*: Jacob “Whenever we did the paper thing, I did more than I was supposed to because I had a lot of fun on it and I just kept clicking and doing the work on it by myself. It got a lot of fun whenever you got to the higher numbers because it was more work and you had a lot more fun with it because of clicking the buttons.”

**Feelings of incompetency or**

*Definition*: This code captures students’ emotions when they describe their fear of failing. This is not failing a class with a grade of an F but failing in completing the work assigned or being unable to accomplish something.
<table>
<thead>
<tr>
<th>Fear of failing</th>
<th>important. Students can also express reservations about their feelings of competency.</th>
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<tbody>
<tr>
<td>Example: Madison “I was nervous because the work was easy because sometimes easy can cause simple mistakes. I made sure I went over my work to make sure those simple mistakes didn’t happen.”</td>
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<tr>
<td>Sarah: “The time that I get nervous from this week and like all the time when I have trouble or something and I call you over it makes me nervous because I see everyone else like getting it and stuff and I feel like I’m the only one whose not getting it.”</td>
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<tr>
<th>Flow</th>
<th>Definition: This code captures students describing a state of flow similar to Csikszentmihalyi’s (1997) definition. Flow describes times when the task’s level of challenge is appropriate for the learner’s skill level. There is just enough challenge to make the task interesting but not so much challenge that the student believes he or she cannot complete the task.</th>
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<tr>
<td>Example: John “Something unexpected I had was writing the script was actually the easiest part… the script was discovering itself. It was like building itself. It was writing itself.”</td>
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<tr>
<th>Freaking out/relieved</th>
<th>Definition: This code captures students’ emotions as they move from frustration or panic to a sense of relief because they have figured out what they need to accomplish or how they can accomplish what they know they need to do.</th>
</tr>
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<tr>
<td>Example: Marissa “I agree with Elizabeth and Jacob because I don’t know what it was called but the one where you had to do the grids and a lot of grids. That one was kind of unexpected because I accidentally pushed the up arrow key and a lot of these grids just popped up and I was kind of surprised and that was kind of unexpected for me because I did have a lot… I had a big number, I don’t remember what it was and I was kind of freaking out about it because I only had like one grid and I was like I don’t know where it is and then I clicked on it on accident and I was like relieved so that was kind of unexpected.”</td>
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<tr>
<th>Frustrated</th>
<th>Definition: This code captures the emotion of frustration for students.</th>
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</table>
| Example: Marissa “It [Thinking Blocks] was a lot. It was very frustrating. You had to put a lot of time and work and energy and your brain and well sometimes like if you knew the steps matter so if you if you just didn’t do one thing right it would just mess everything up for you. Your mind got scattered. Then we tried to solve the problem and drag the boxes to the little
rectangles… it was kind of too much. All this stuff and it just made me very angry.”

**Fun**

*Definition:* This code captures the emotion of fun for students.

*Example:* Becky “Another time was… another time when we did the fraction to percent, I thought it was so fun that after you told us to stop and after you told us to go home I got back on my computer and did it again until it was time to go to bed.”

**Fun versus learning**

*Definition:* Students were describing an internal struggle with the amount of fun they could expect from their homework. They wanted the work to be fun but they also sensed that homework was not supposed to be fun. This was in contrast to the work they had in class in which they appreciated when it was fun.

*Example:* John “Same thing as Sarah, it would be nice to have fun factor in there but sadly it's homework. Homework can be fun, but to an extent. And in my view, you can't really have a game with homework. Because you have study. You may get too distracted with all the… with the world… like you have to have like something to keep you entertained, right? When games are bored and you may focus more on the game aspect than the board. And that's why it’s fine to have like just questions.”

**Gaps in knowledge**

*Definition:* This code is used when students demonstrate a gap in their knowledge. They could realize the gap or it could still be an unrealized gap in their knowledge. They are not necessarily making a connection to another piece of learning, they are just realizing there is more to learn.

*Example:* Allison “I don’t really think I did [do more than was required] this week because since I was just learning how to figure out percents so I don’t think I did.”

**Going at your own speed**

*Definition:* This code is used when students note that the speed at which the work progressed was satisfactory to them.

*Example:* Matthew “The easiness of the work made it kind of interesting because I could do it very fast, but that is also why it is not interesting, because it was not much of a challenge.”

**Group dynamics**

*Definition:* This code began as a way to capture all of the interactions described between the groups of students during their two weeks of group work. As the code evolved and the researchers explored the coded portions of the interviews, many of discussions surrounded social construction of knowledge, which then became a separate code. Left in this code was
students’ discussions of their roles and responsibilities to the group.

**Example:** Marissa “The complex or challenging thing we did in Math Out Loud would be the script because as we were working like some of us had already gotten done with our jobs that we were assigned and [two other students] were typing so we were done with everything. By the time we got there to record, we didn’t really know what we were doing. Like there were a lot of parts that we didn’t assign to who was going to say what and a lot of people were just jumping in saying all kinds of stuff and then when we went to say the word, everybody had a different letter and it was kind of confusing. Then people would get tongue twisters and didn’t say the word right and it was just like really off.”

**Happy**

**Definition:** This code is used to capture the students’ emotion of happy.

**Example:** “A little frustrated that I had to change my answers but a little happy that I learned something new.”

**Hard fun**

**Definition:** This code captures a fun that is distinct from the fun code described above. Using this code captures Papert’s hard fun, which is a fun that is not whimsical, but that is challenging and requires thought and effort to complete. It is that challenge and effort that makes the work fun.

**Example:** Madison “I enjoyed resizing the images. It was just fun. It still was fun and it gave you a challenge to help with ratios because you can’t learn it if you don’t have a challenge.”

**Initiating behaviors/Goal oriented behavior**

**Definition:** During observation, students are clearly working on the task at hand with the goal of completing the work to the best of their ability. During interviews, students can discuss their goals in completing the work. Sometimes, the students’ goals are different from the teacher’s goals, but this code should not be used for goals that would be considered counter to the learning at hand. If students adopt a playful goal but are still engaging in the work and completing it, it can be coded as goal oriented behavior.

**Example:** Sarah “I think what happened with on my math cast because I stuttered a bit. Like I practiced and everything, and when I recorded and when I said things I made revisions in my head and no that wouldn't sound right. And when I put it out it sounded all weird and I tried to say everything and it turned out weird.”

**Intrinsic reward**

**Definition:** When students were doing the work for the sake of learning and not some external reward, it was coded with intrinsic reward.

**Example:** Becky “Even though it is not in our block but I still wanted to look up there [on the storyboards]. And as I come into the classroom, I always stop and read each board and I was going to ask you if we could like listen to everyone else’s during class.”
<table>
<thead>
<tr>
<th>Definition</th>
<th>Example</th>
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</table>
| Invented play | This code is used when students create an environment of play beyond that which is requested by the teacher. Students created competitions that involved many students or just played little mind games with themselves.  
Example: Karen “We had a little competition on how much we did and I think it was Becky who got the most and I got like 49 and yeah. It was really close.” |
| Inventive problem solving | This code is used when students create their own way to solve a problem rather than the “official” steps designated by the teacher or the most efficient steps known by the mathematical community. It is usually found before the official steps are taught because once the steps are taught, students tend to want to use those steps so that they know they are doing the work “correctly”.  
Example: Madison “A time when the work was complex or challenging was the example and pronouncing the word parallel-a-rail. That was kind of challenging because we were reading it off of the paper and we didn’t know which way we should pronounce it or how many l’s or what does this say. It was kind of hard.” |
| It’s virtual | This code is used when students adopt the stance that tasks can be completed more easily, quickly and efficiently if they use technology to complete it. Technology can also be described as compelling, authentic or realistic.  
Example: Marissa “It’s virtual. And you don’t have to use pencils and all that stuff. Then what if you don’t have a pencil… I’m just saying! It’s just fun.” |
| Lack of purpose or organization | This code captures students’ descriptions of times when they were unorganized, did not understand what they were supposed to be doing, or why they were being asked to do the work.  
Example: Sarah “I think Madison said it with trying to figure out which one to do. Because I forgotten where I had left my paper. And I had forgotten what you said. So I was like, going, which one should I do.” |
| Leveraging resources/ Knowing self as learner | This code is used when students express some strategy that is used to help them in a difficult situation. They are demonstrating that they can self-assess that they are in a challenging situation and that they have tools they can use before they ask someone else for help.  
Example: Allison “I think the Thinking Blocks were challenging. One because I always had to press hint before I could press check. That was weird. And then just like reading it, it was challenging because I had to visualize it and I had to write it down and hear it too. So I had to like do all” |
this to understand it. So I had to get that piece of paper again and write it
down cuz it was making me mad because I couldn’t do it without the paper.
And I sort of read it as a whisper so that I could hear myself. I have to hear
it, visualize it and write it down too or I just don’t see it. So that was making
me mad. So I was reading it to myself and I was looking at it and I wrote it
down and it was less complicated.”

<table>
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<tr>
<th>Maintaining Focus/Engaged</th>
<th><strong>Definition:</strong> This code is used when students are consistently on task and working toward completion of the learning at hand. Sometimes students will become off task for brief moments in time. If these moments are short and the students move back to on task behavior without any prompting from the teacher, they are still considered engaged.</th>
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<td></td>
<td><strong>Example:</strong> Sarah “For me I think it was when we were trying to, when we were thinking what we were going to say for the math casts. I was partners with [another student] and he kept telling me what the answer was. And I was still doing it in my head, because you also have to think of what you are going to write down and what you are going to say. And I was sitting there for a long time just thinking. And I think that was really it.”</td>
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<tr>
<th>Making connections</th>
<th><strong>Definition:</strong> Students can be making connections to prior learning or to prior work that we have done. This is more general than the pulling together fragments into coherent knowledge structures code because the connections can be from any work and don’t necessarily need to lead to knowledge structures. It is also different from the aha! code because the aha! code is used for very general discoveries.</th>
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<td></td>
<td><strong>Examples:</strong> Madison “The thinking blocks reminded me a lot of drawing a model like we used to do except it was virtualized” Thomas “The fact that we used old manipulatives like somebody else said… like John said. And, that’s pretty much it. … Surprised I guess that I didn’t think we would be coming back to… I almost forgot about that lesson and it brought it back up and I remembered and I was like, “oh, yeah. I remember that.” So surprising really.”</td>
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</table>

<p>| Material intelligence | <strong>Definition:</strong> This code also comes from Gee’s book <em>What Video Games Have to Teach Us about Learning and Literacy</em>. His learning principle is called the material intelligence principle which means that “thinking, problem solving and knowledge are ‘stored’ in material objects and the environment. This frees learners to engage their minds with other things while combining the results of their own thinking with the knowledge stored in material objects and the environment to achieve yet more powerful effects.” This code is used as students talk about certain ways the technology helped them as they were learning. |</p>
<table>
<thead>
<tr>
<th>Not enough time</th>
<th><strong>Definition:</strong> This code captures students’ laments about the limited amount of time available for a particular piece of work.</th>
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<tbody>
<tr>
<td>Example: Sarah “What was nervous for me was the first day we were doing when we were trying to get all the cards done we were kind of nervous that we weren’t going to get our hook just because we were running out of time. We ended up not getting the hook done. It just made us nervous anyways.”</td>
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<tr>
<th>Novelty</th>
<th><strong>Definition:</strong> This code captures when students explorations were due to the novelty or newness of the technology as opposed to the mathematical concept being studied.</th>
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<tbody>
<tr>
<td>Example: Allison [describing exploring with the Study Buddy™] “When I first got it, and now I don't explore anymore, I just do my work.”</td>
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<thead>
<tr>
<th>Persistence</th>
<th><strong>Definition:</strong> Students continue to work even when confronted with challenge or frustration or when the allotted time has expired.</th>
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<tbody>
<tr>
<td>Example: Becky “I think I was searching for more information when we were doing decimals to percents because I was like after you told us to stop for like the last five minutes of class I still had my computer out, I was still going because I really liked doing it. I was trying to see how many more could I do and challenging myself to do more.”</td>
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<tr>
<th>Pulling together fragments into coherent knowledge structures</th>
<th><strong>Definition:</strong> Students demonstrate some new understand, particularly by identify small bits of information that they now see are connected. This is different from the making connections above because making connections does not require that students are access small bits or that they are creating knowledge structures. This is also different from the aha! code because it is very specific in nature. The aha! code is used for very general successes or discoveries. This code is used for very high levels of thinking.</th>
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<tr>
<td>Examples: John “I agree with Matthew, Madison and anyone else who said that because, it is. Because they are already like converted for you and they are already in base 10. While fractions can be in any base and it kind of throws you off so you have to make them equivalent and all that.” Becky “I think the decimal to percent is easier because [another student] taught me how to put it, a decimal to percent because all you have to do is take off the zero and I said, “Oh, that’s all you have to do.” It’s like “Yeah because…” and then she kind of like drew a chart explaining like how it is the same its just a 10, like each bar equals 10 like 10 base blocks so when I learned how to do it I finished very quickly.”</td>
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<tr>
<th>Pushing</th>
<th><strong>Definition:</strong> This code is used when students are pushing technology to the</th>
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technology to its limits

limit to see what it can or will do. Sherry Turkle discusses this concept in her book The Second Self (p. 40). Essentially, children will “kill” technology so that they can bring it back to life. It is about pushing the machine or the software to its breaking point so that the user knows its limits. It is also a way to play with the technology and feel powerful when you can bring it back to normalcy.

*Example:* Madison “The thing that I found unexpected was decimal to percents. I had to get more grids. I accidentally held the touch pad too long and it went up to 1000 grids and I got it right on my first try! And it was like 1.03. I got it right!”

### Seeing possibilities

*Definition:* This code is used when students adopt a prosumer stance (Tapscott & Williams, 2006) in which they desire the ability to change a product that they are not satisfied with to more fully meet their needs.

*Example:* Thomas “A digital textbook, that's practically all it is. It doesn't do anything fun, it's just answer questions. It mean it would be more fun if it was a kind of video-game style. It would have a certain thing and ask you a problem based on the problem and information instead of one, two, three, four, and a, b, c, d and blah, blah. That, it's not exactly fun.”

### Seeking help

*Definition:* Students can seek help from peers, teachers or from the technology itself.

*Examples:* Thomas “I might have had some help along the way from [another student].”

Becky “I kept getting this one wrong and I called you over and you were saying how it was just like an improper… I forgot… percent… it was…”

### Seeking more information

*Definition:* Students are actively looking for more information. This code is used when students are seeking or searching.

*Example:* Olivia “I think the hook and the etymology was harder because like the words are mathematical so they are like hard. My word, I couldn’t find it in the math book or any of those books so we just got on a laptop.”

### Self conscious

*Definition:* This code captures students’ feelings of self consciousness. It could stem from not feeling competent with the work or from the fact that the work is shared with a wide audience.

*Example:* Sarah “The time that I get nervous from this week and like all the time when I have trouble or something and I call you over it makes me nervous because I see everyone else like getting it and stuff and I feel like I’m the only one whose not getting it.”

### Self evaluation

*Definition:* This code is used when students were being metacognitive, evaluating themselves and where they are in their learning. They did not necessarily have to take action on their thoughts. This code just captures the
<table>
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<th>Code</th>
<th>Description</th>
<th>Example</th>
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<td>students thinking about their self evaluation.</td>
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<td>Elizabeth “Whenever I had a number it was way too easy. It was just like zero and nine hundredths. It was kind of boring because I just kept on getting really easy ones so I was, I would go to the next problem and if it was a hard one then I would do it.”</td>
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<tr>
<td>Sketching math</td>
<td>This code captures students discussions of the sketching they did to model their mathematical concepts.</td>
<td>Becky “I think the decimal to percent is easier because [another student] taught me how to put it, a decimal to percent because all you have to do is take off the zero and I said, “Oh, that’s all you have to do.” It’s like “Yeah because…” and then she kind of like drew a chart explaining like how it is the same its just a 10, like each bar equals 10 like 10 base blocks so when I learned how to do it I finished very quickly.”</td>
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<tr>
<td>Social construction of knowledge/Finding consensus</td>
<td>This code was used as students discussed their construction of knowledge with each other or with the world.</td>
<td>Olivia “The hook was a bit hard like there was like a lot of, but not some very good ones and then everybody wanted their idea to be in it. And so it was very complicated.”</td>
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<tr>
<td>Social responsibility</td>
<td>This code captures students’ struggles with the responsibility required to bring technology back from home on time and in good condition so another student could use it. It also captures students’ struggles with wanting more technology, but understanding that it is expensive. They did not want to appear greedy but they did want more technology.</td>
<td>Madison “I am not saying that anyone here is ungrateful for anything. But you guys have got to be kidding me. You guys want all of these extra features that can cost like at least 100 bucks a piece. If you guys want all of this special new stuff and want it to have this. There is like 65 kids in this grade. And who knows how many more are in the next grade that will have to use this. You have to think if someone loses it, if it breaks, or something happens to it, how much money is it going to cost to fix it? Or to at least buy a new one.”</td>
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<tr>
<td>Social scaffold</td>
<td>This code describes scaffolding that students received from other students. It is different from seeking help because the students do not indicate that they sought any assistance, just that the scaffold was present. It is also different from social construction of knowledge because it was not described as a process of negotiation, just described as assistance that some other student offered.</td>
<td>Madison “Well, I didn’t know what etymology was until John started talking about it and then it came back.”</td>
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<tr>
<td>Technology impediment</td>
<td>This code captures students’ frustrations with technology getting in the way of their learning. The scaffolds that the technology is offering did</td>
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</table>
not help the student or if they helped at one point, they were no longer helpful.

*Example:* Sarah “… when you were doing the thinking blocks you would kind of get lost doing it because there was so many steps and then you forget what you were doing and you would have to look back on it and then you would just get lost. And then with the work that we did today with the having the paper too you had to do one thing and then you had to do the paper also and I thought it was just really difficult.”

**Technology scaffold**

*Definition:* This is when technology is used as a scaffold for students’ learning. This is specifically for positive (welcome) scaffolds, not negative (unwelcome) scaffolds.

*Example:* Marissa “some of them they kind of gave you the answer but you had to find the rest. So it was kinda good. I liked it”

**Technology vs math**

*Definition:* This code documents times when the technology competes with the math in how students understand the problem. Some concept might have been lost in translation between the technology and math.

*Example:* Kiara “the hard part for me was when we had to put it on paper because it was easier for me to put it on paper because I didn’t know what the difference was between the two. Because I couldn’t tell which part was which because the headings were different from with when it was on the computer. So…”

**There’s something wrong with my computer**

*Definition:* This code was used when the student blames the computer for their misconceptions.

*Example:* Madison “I don’t think the base blocks [Thinking blocks] liked me because I would put in the right thing and it popped the question up again and it wouldn’t let me answer and so I had to swap the numbers around when they were the wrong numbers.”

**Thinking past the question and stuff/Remote transfer**

*Definition:* This code is used when the student generated a new type of question beyond the original assignment. The student does not necessarily need more information to accomplish their new goal. They feel they have the information and tools they need, they just need the time to explore the new question or they are transferring their knowledge to a new situation.

*Example:* Matthew “I agree with Marissa on this point that the island game really got me thinking past what it had on the questions and stuff.” Madison “there was this one question where I got like 4.67 and umm I thought that ummm… would this be a real percent if it was originally created to be that. It made me want to think about that. Luckily it was my last
<table>
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<tr>
<th><strong>Trial and Error</strong></th>
<th><em>Definition:</em> This code captures students’ discoveries that were made almost accidentally. Students did not approach their explorations methodically.</th>
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<td><em>Example:</em> Madison “The thing that I found unexpected was decimal to percents. I had to get more grids. I accidentally held the touch pad too long and it went up to 1000 grids and I got it right on my first try! And it was like 1.03. I got it right!”</td>
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<td><strong>User inexperience</strong></td>
<td><em>Definition:</em> This code captures students’ descriptions of their struggles with technology due to their inexperience with it. These were not struggles with the mathematical content. Nor were they struggles with the way the technology was scaffolding the learning. They were simply frustrations because the students were unfamiliar with the technology itself.</td>
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<td></td>
<td><em>Example:</em> Olivia [describing her first experience with the Study Buddy™ device] “When I first got it, because I couldn't find the power switch. I pressed all the buttons that I saw until, it was like this little switch. I didn't want to click it because I thought it would do something bad to it. And then when I clicked it, it turned on and I then didn't have the cartridge in it. And I was trying to figure out how to put it in. First I put it backwards. And then I accidentally closed my eyes and put it in backwards again. And I was there like 10 times, doing it 10 times until I first started.”</td>
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<td><strong>Visual modeling</strong></td>
<td><em>Definition:</em> Students discuss the benefits of “seeing” the mathematical concept or model as an aid in understanding. The visual vocabulary should be present in the students’ statements.</td>
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<td><em>Examples:</em> Elizabeth “I like the resizing the images better but also because instead of just having to work it out on paper with everything written out, you can kind of understand it but when you actually see it you really know what you are doing.” Sarah “And yesterday it was kind of interesting because it was something that I didn’t really know and with the T chart and everything you could see it and it wanted me to like do it more so I could like understand it better.”</td>
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<td><strong>Wide audience</strong></td>
<td><em>Definition:</em> Students attribute their work to the presence of a wide audience outside of the classroom. Usually, this is in reference to work that is posted online for the world to see. Students create a high standard for themselves when their work is created for a wide audience.</td>
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<td><em>Example:</em> Matthew “What made me nervous is recording the script because whenever we do something like that I always get nervous that I’m going to mess up.”</td>
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REFERENCES


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Hannafin, M. (1981). Effects of teacher and student goal setting and evaluations on mathematics


psychometrics. *Journal of Research in Personality, 43*(6), 987-998.


Chen (Ed.), *Cases on Educational Technology Integration in Schools*. Charlotte, NC: Information Age Publishing.


