MIDDLE GRADES STUDENTS' MATHEMATICAL PLAY USING TECHNOLOGY TOOLS

by

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(Under the Direction of James W. Wilson)

ABSTRACT

The purpose of this study was to investigate linkages between students' mathematical play, affective experiences, and cognition. The study was conducted in the researcher's seventh grade mathematics course. Students experience with school mathematics changed when they entered a course driven by problems and requiring articulation of mathematical reasoning in support of assertions and solutions. In an effort to mediate the transition a variety of non-standard pedagogical approaches were incorporated. Under investigation in this study was the influence technology tools providing a microworld governed by mathematical rules, The Geometer's Sketchpad and Microsoft Excel, had in provoking a student's engagement, playful activity, and its influence on a student's affective experience. The data is largely drawn from four students created files and video recordings of experiences solving problems over a two-month period. Using student expression of emotional experience to focus the analysis of their engagement, this study offers insight into the influence of affective experience during engagement with school mathematics. Results suggest technology tools can provide students opportunities to engage in a broader range of activities playfully. These opportunities to play promoted affective experience, which supported continued engagement with problem solving and the learning of significant mathematics. Further conclusions link a student's goal orientation to the nature of their playful activity. Implications for student mathematics learning, teaching practices, the incorporation of technology tools, and student motivation to engage in school mathematics are offered.

INDEX WORDS: Mathematics education, Problem solving, Mathematical play, Technology in school mathematics, Affective experience, Goal orientation

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CHAPTER 1

Rationale

In the current climate of mathematics education there are multiple voices encouraging a rethinking of practices in the mathematics classroom (Center for Science Mathematics and Engineering Education, 2000; Kilpatrick *et al.*, 2001; NCTM, 2000). Teachers are encouraged to develop problem-based tasks and to put the student's thinking at the center of the class's activities. Teachers are also encouraged to incorporate technology tools in mathematics classes to support student learning (NCTM, 2000). Curricular materials have been developed and a variety of professional development endeavors conducted to support teachers to align their practice with these goals for a student's experience with school mathematics. Although there is evidence of student understanding and achievement regarding such classroom practice (Senk & Thompson, 2003), there is a need for evidence of the impact such changes may have on a student's affective experience with school mathematics (Chappell, 2003; Hart, 1989; McLeod, 1992).

The mathematics class is a setting where a variety of experiences occur for a student. It is a setting where a student may learn mathematical concepts and procedures. During these experiences with school mathematics, a student's motives to learn the content and emotional experience in the classroom and with mathematics are factors in how the student expects to engage and on what is learned. As a student proceeds from one level to the next and similar environs are experienced, these habits of engagement with mathematics class become more stabilized These experiences lay the groundwork for a student's expectations about school mathematics (Boaler, 2002).

When a student's experiences with school mathematics have been reasonably consistent, the expectations one holds for success or failure, interest or boredom, or anxiety, frustration and fear are likely firmly established after experiencing them for more than half a lifetime. If a student is then thrust into a new setting that differs widely from past experiences, these expectations are not realized and in fact may be contradicted in significant ways. Such a shift in approach to school mathematics necessarily forces a student to confront a transition in engagement with school mathematics. The transition from one setting to a different one necessarily impacts the transactions between a student's cognition, motives, and emotional experience while engaged in a different fashion.

Take, for example, a student who has largely experienced school mathematics in a teacher-directed classroom. This student is likely to expect a teacher to work from the front of the classroom, to present example exercises on the board or from an overhead projector, to give an assignment designed to allow for practice of the particular procedure demonstrated in front of the class, and to check the answers the student generates for correctness. During experiences such as these with school mathematics, a student develops expectations for 'math class' reflecting these practices. Now, consider what is experienced when this student is assigned to a class driven by principles valued by those calling for a rethinking of practices in mathematics classrooms. Here the student is likely to experience a setting where students are responsible for the directions in which the class will move. Rather than being told what to do and shown how to do it, a student in such a setting must first determine what is expected, plan how to accomplish (or avoid) this expectation, and then figure out how to carry out the plan.

A student's affective experience influences how the student adapts to the various aspects of transition encountered, if changes are.   Moreover, these transitions encountered may promote positive affective experience and increase motivation to learn about the course topics. Such a transition may produce negative affective experience, however, if the student does not understand how to operate in a setting different from what is expected. I suggest it is more likely that a student will be influenced by a variety of productive as well as debilitating affective experiences during such a transition.

Pedagogy is central to a student's experience with school mathematics, and thus integrally tied to any transitions a student confronts. For me, the opportunity for students to experience pedagogy consistent with the principles shaping the rethinking of practice in school mathematics is both possible and important. This belief and my values shaped by experiences with school mathematics as a student and teacher, bind me to a goal that students have opportunities to experience school mathematics in such a way. Hence, supporting the transition a student encounters becomes necessary.

In an effort to promote productive experiences for students during a transition period, several pertinent aspects need be considered. These include the previous experiences of the student with school mathematics and how these experiences shaped the student's expectations of school mathematics. These aspects are important given the role a person's expectations for a setting have in the formation of the goals the individual pursues when experiencing new conditions. Assuming the theoretical stance that one's goals directly influence the individual's motives, thinking and feelings, a student's prior experiences with school mathematics and expectations for such a setting are important. Additionally, because I believe the transition students will encounter is dynamic, it is also important to consider ways the course may be adjusted, as time progresses, to best suit the students.

Students in the middle grades are the most important subgroup of K-12 students to support in a transition of school mathematics. One reason to attend most closely to these students is the stage of life they are in and its inherently volatile nature given the many physiological changes taking place. It is also at this time in a student's academic career that motivational issues are paramount (Anderman & Maehr, 1994). Thus, supporting a transition between pedagogies is particularly important with students at this level given the motivational and emotional aspects of these students' school experience. Additionally, and most importantly for me, in the middle grades, school mathematics becomes more generalized as the content tends to transition from arithmetic to algebraic and geometric ways of operating. Therefore, not only do middle grades students encountering a transition between pedagogies have to contend with different methods, they are also forced to contend with abstract reasoning that in and of itself can provide significant transitional factors.

The chance to engage in mathematical activity playfully theoretically lends to the conceptual learning of mathematics and also makes it possible for a student to have an improved "quality of experience" (Schiefele & Csikszentmihalyi, 1995). Hence, mathematical play in school mathematics may favorably influence student affective experience. Assuming a student does not know how to engage in mathematical activity playfully, which seems reasonable given the ever-growing 'seriousness' of schooling, the teacher must support the student in this endeavor.

Given a transition between pedagogies is going to occur, one way to support students is to incorporate opportunities to play, specifically for middle grades students to engage in mathematical play. A way to provide this support and facilitate the mathematical play of middle grades students is to engage them in problem solving with technology tools. In particular, I refer to software applications that provide a microworld, directed by mathematical rules, with which a student interacts. The nature of the microworld may allow one to play. A teacher then could strive to focus the playful activity of the student towards mathematical play. Thus, mathematics learning is supported as productive affective experiences are promoted. Therefore, mathematical play may be particularly powerful to support a student experiencing a transition in school mathematics.

As an avenue to test my conjecture, I took on the role of teacher/researcher in a middle school. I developed a course requiring students to transition to a different kind of mathematics class than they were accustomed to. Throughout the academic year I attempted to support student mathematical play. All the while I attended to the students' affective experiences were influenced by their experiences in the course. My efforts to promote and study these constructs were informed by questions of:

> How does the opportunity to use technology tools while engaging in mathematical problem solving provoke a middle grades student's mathematical play?
>
> and
>
> If mathematical play occurs while a student is using a technology tool, what influence does the action have on the student's affective experience?

Learning more about a student's mathematical experience during such a transition may support other mathematics teachers as they experiment with their practice - to align with a particular vision of school mathematics. It is within classrooms that such changes must take place (Hiebert et al., 1996). Thus my study has potential to be meaningful for other educators. Additionally, more knowledge about using technology tools in school mathematics will be gained as a result of investigating my conjecture. Third, by investigating the questions above with attention always dedicated to the transitions students encounter, I intend to gain greater understanding of how the transactions between emotional experience, motives, and cognition influence students while in a mathematics classroom.

CHAPTER 2

Literature Review

My in-context research necessitates students have opportunities to engage in solving problems. I first address literature relevant to mathematical problem solving since that is a central aspect of my research. I follow the problem solving literature by describing literature relevant to the connections between mathematical problem solving and the technology tools I made available to the students involved in my class. Next, because affect is critical to the transition the students will encounter at multiple levels, I address literature leading me to my conceptualization of student affective experience. Fourth, the description of mathematical play and its theorized connections to affect that inform my thinking are offered. Finally, I present a cursory nod to other related aspects of my research problem.

Problem Solving

Mathematics educators tend to divide our field of inquiry into a number of subcategories. These delineations could be organized around content and topics such as number theory, algebra, geometry, and others. The National Council of Teachers of Mathematics (NCTM) not only divides mathematics by content but by processes that are involved in the study of the subject in school as well. This group lists these processes as communication, representation, reasoning, connections and problem solving (NCTM, 2000). It is my opinion that the last of these, problem solving, is synonymous with original mathematical activity. There are opportunities to solve problems in any portion of mathematics content, and to be truly proficient at problem solving one must be able to use the other four "process standards" (NCTM, 2000). Thus problem solving spans the field of mathematics regardless of how one divides the domain.

Polya’s work is key to the conceptualization of problem solving informing this study. He defined a problem as a mathematical task for which an individual does not have a ready strategy to determine a solution. He described four phases one may experience to solve problems (Polya, 1957). Polya’s phases consisted of first understanding the problem. Having used strategies to understand the related nature of the components of the problem and the eventual solution, one next must devise a plan to reach the solution. Polya advocated a teacher pose questions to the problem solver to support devising a plan (Polya, 1962). The third phase includes carrying out the plan, paying attention to each step along the way. Finally, Polya advocated looking back and examining the plan and solution, how they may be useful to solve other problems, or if one could make an adaptation to arrive at the solution in a different way.

He also discussed the parts of a problem. At first, this explanation seems ridiculously simplistic and unnecessary until I consider the vast multitudes of people who struggle with mathematics and how thinking of a problem in such terms may tie to his phases and thereby further an individual’s problem-solving efforts (Polya, 1962). Polya described the parts of the problem as the unknown, what we are attempting to find; the given(s), the information that is provided to the solver of the problem; and the condition, the interrelationship of the given information. Considering the problem in this manner not only allows one to make use of Polya’s phases in an effective fashion, but the individual also has at hand a language to categorize the aspects of the problem so that the fourth phase of Polya’s list will have added value (1962). Polya further stated the mathematics teacher held considerable power to support students’ developing thinking by creating opportunities for original mathematical activity. Polya’s efforts to describe a process, offer strategies and tactics, and to consider the teacher’s role while students are solving problems have provided a sufficient categorization of problem solving for this study.

Polya described an admirable perspective to approach solving a problem and ideas for teaching problem solving, Schoenfeld proposed an explanatory framework for analyzing the mathematical behavior of the problem solver. He, in doing so, provided a theoretical basis so that mathematics teachers and researchers may gain a greater understanding of the activity of the individual engaged in problem solving. This framework consisted of four categories; resources, heuristics, control, & beliefs (Schoenfeld, 1985). For Schoenfeld, resources consisted of the individual's available mathematical knowledge. He built on Polya's efforts to rekindle the study of heuristics by including these techniques as the second category of his framework. Third, Schoenfeld identified the control of the student to deploy knowledge of mathematics and problem solving strategies as a critical aspect of mathematical activity (1985). As the final category of mathematical activity, the belief systems of the individual were considered. Beliefs are described as establishing the context for the operation of each of the three previous categories, and therefore are vital to the mathematical activity of the learner. This condition is relevant because the learner's beliefs about mathematical knowledge and its usefulness for a given problem determine what knowledge may be applied (Schoenfeld, 1985).

Subsequently, in his chapter in the *Handbook of Research on Mathematics Teaching and Learning*, Schoenfeld described his framework with five categories. These consisted of the knowledge base, problem-solving strategies, monitoring and control, beliefs and affects, and practices (1992). Holding firm to the first three categories of his earlier framework, Schoenfeld added affects to the category containing beliefs. In this effort he discussed beliefs from the standpoint of the student, the teacher, and society, but left the discussion of the affect of the student to McLeod (1992). In discussing practices Schoenfeld referred to the environment of the classroom and the epistemological stance of the teacher for determining the choices made in the direction of a course (1992). This aspect is worthy of a role in a framing of mathematical activity. This framework focuses my thinking about and descriptions of student's mathematical activity.

Using technology while problem solving

The technology used in mathematics teaching and learning is a vast set of tools that are changing and advancing rapidly. One could conceive of technology that makes it possible for a teacher to present a more dynamic lesson. Take, for example, a computerized presentation and projector that a teacher uses to teach a particular topic. The ability to incorporate animated graphics, video, and other eye-catching effects draws some educators to implement such technology tools into their classrooms. Tools such as these, however, may have an effect across various subject areas of the school curriculum. In an effort to streamline my discussion of technology, I intend to only consider those tools that find a place primarily as tools for doing mathematics and their use in school mathematics. Further, I dichotomize these tools into categories. One such category includes technology tools that 'tell students what to do' such as remediation software or programs providing rewards for performing computations accurately and/or efficiently. The second category includes the tools used by students in this study. These tools provide a structure within which a student may operate mathematically, but the student is not 'told what to do.'

If one accepts that a learner has a limited amount of cognitive facility to dedicate to a problematic situation at any one given time, then technology tools allowing a student to focus on aspects of a problem other than computations can make it possible for the student to make more effective use of cognitive resources. If a student need not be concerned with tedious computations, then the focus of energy can be toward other aspects of engagement. Interviews I have conducted with middle grades students suggest this role of technology is important and valued by students (see Appendix 7).

Kaput (1992) addressed a number of issues worthy of investigation regarding the use of technology tools in school mathematics. Each could be considered from four dimensions with regard to analysis. These dimensions are the relationship to teaching, the connection to the learning of mathematics, the relationship to the larger context of schooling itself, and finally to the technology itself (Kaput, 1992). I focused analysis on student learning with constant consideration given to the role of technology tools. Another avenue of inquiry raised by Kaput (1992) pondered the question of representational notations and methods to link multiple representations. He also questioned the balance between the use of physical and computerized materials, inquiry lessons and coverage of the subject, and raised the concern focused on the supportive role of software to promote students work with problems. Although these questions are not the main focus of this study, each did present itself in a reoccurring fashion during the duration of the study.

Affect

In an effort to explicate the theoretical connections between mathematical problem solving, affective experience, and mathematical play I next describe my conceptualization of affect. A variety of descriptions of affect are offered in scholarly literature. For some the affective domain consists of the moods and emotions of the individual (Linnenbrink & Pintrich, 2003). At the intersection of the study of affect and the study of mathematics education other scholars are inclined to describe affect more holistically and see it as encompassing one’s emotions, attitudes, and beliefs (Hart, 1989). Further still, affect is described as consisting of the above as well as the values, ethics and morals of the person (DeBellis & Goldin, 1997). Since emotional experience during activity is, affect is also dynamic. Thus to describe to student affect during activity, I refer to the student's affective experience. Further, I contend the individual's goals are central to the trajectory that a person's affective experience takes during activity. Because goals are cognitive and critical to the framing of motivation for this study, I interpret affective experience as the transactions between cognition, motives, and emotional experience.

Cognition

My beliefs about one's ways of coming to know lie in the domain of constructivism. Piaget's statement that we organize the world by organizing our mind is an excellent way to summarize how I see the process that a human must undertake in order to develop understanding (von Glasersfeld, 1995). Piaget described the aspects of cognition as figurative and operative. Although the figurative facet of cognition is viewed as a static imitation of states, the operative portion of thought consists of transformations from one state to another (Piaget, 1970). I will focus my efforts on the operative aspect of thought for it is these actions of transformation that allow knowledge to develop and become adequate for the individual's purposes. Piaget (1970) stated the action one undertakes with an object can also be carried out mentally; therefore, the abstraction made by the individual need not be drawn only from the object, but it is rather facilitated by the action itself. The action relevance of cognition is further described to take the form of a reflective abstraction. It is based not only on the individual's actions with objects but rather on the coordinated actions organized to attain a goal. These coordinated actions take a variety of forms but, in short, the action of this coordination is thought to be the basis for the development of logical structures (Piaget, 1970). The concept of scheme derives from the repeatable and generalizable aspects of the coordination of actions. Most constructivists contend learning is a process of actively constructing such schema. Further, assimilating new experiences to existing schema and making accommodations to construct schema anew are each aspects of the cognitive processes of individuals and thus an aspect of the process of how we come to know our world.

What aspects of human experience make it necessary for one to enact the proffered coordination of action required to make sense of a given situation? The notion that humans experience the described process of reflective abstraction when confronted with an occurrence that creates a form of disequilibrium in the system is pivotal to this epistemological stance and the necessity to act. The action taken by the individual is viewed as the effort to neutralize the perturbations that produced the lack of equilibrium in the system (von Glasersfeld, 1980). For von Glasersfeld the system necessarily has a goal to deal with the perturbation in some fashion so as to return to the state of equilibrium. Thus the perturbation that produced the system's disequilibrium is the trigger for the action of the individual's reflective abstractions. This action to restore equilibrium allows one to come to gain knowledge and develop an optimal level of connection between this knowledge and the world. The knowledge that is produced cannot, however, be of a universal reality supposed to exist, but instead this coming to know is a process of remaining viable in one's environment and adapting to return once again to a state of equilibrium (von Glasersfeld, 1980).

Piaget's construct of reflective abstraction making this action possible is further discussed by von Glasersfeld (von Glasersfeld, 1995). He stated this abstraction as discussed by Piaget operates at two levels. When the abstraction was connected to conscious thought, Piaget termed it 'reflected' abstraction. Those aspects of abstraction, which are pseudo-empirical or reflective, were said by Piaget to organize themselves at a different operational level. I interpret this to be an unconscious level. Thus I accept the stance human experience is not static, but rather I align myself with the belief of von Glasersfeld, a constructivist "accepts without question the dynamic notion of living" (1995, p. 111). Therefore, if humans live and function in a dynamic system, a variety of aspects defining an individual in a particular environment have an impact on efforts to produce equilibrium and remain viable.

Motivation

A discussion of motivation, its connections to cognition and the questions posed for this study may be focused by choosing to describe constructs related to the achievement motivation of students. Two oft discussed constructs of achievement motivation have been described as a learning goal orientation as compared to a performance goal orientation (Dweck & Leggett, 1988), as task-involved or ego-involved (Nicholls, 1984), or driven by mastery goals or performance goals (Ames, 1992). Although conceptual differences between these terms could be discussed, there is a great deal of similarity between these characterizations of achievement motivation. I primarily use the work of Ames (1992) to facilitate my discussion of student achievement motivation. A central component of a mastery goal orientation is the belief that effort and outcome vary directly. Students with this form of goal orientation are motivated intrinsically by the value they place on learning the particular content (Ames, 1992). On the other hand, a central component driving a student's performance goal is one's sense of self-worth as it derives from ability. Here ability references the student's position compared to the other students through the achievement of good grades, being seen as intelligent by the others, and competing to be the best. This comparison to others is directly related to the particular goal orientation, namely that learning is the way to achieve the goal of performing better than others

(Ames, 1992). Since achievement motivation is characterized by its goal directive behavior, thus connecting the cognitive and affective aspect of an individual's activity, this characterization of motivation aligns with my epistemological stance and the work of educational researchers (Schutz, 1994).

An important connection binding activity viewed as primarily motivational to cognition uses the relation between a student's goals and the specific task. In making an appraisal of the problem each student is prompted by their actions related to the assignment and their goals (Lazarus, 1991). Although some researchers suggest an appraisal is inherent to one's knowledge (Weiner, 1986) and others conceptualize appraisal as an aspect of cognition estimating the importance of knowledge relative to a task (Lazarus, 1991), the appraisal focusing the goal-directed behavior of the student is cognitive. Thus the cognitive realm of the student is seen to directly impact the goal-driven motives to engage in a task.

Since students may have different goals at a given time, recognizing what is driving a student is important. Further, as integral to my teaching methods, I want to promote mastery goals. Thus an awareness of extrinsic motives inherent to schools and the effects of these on more intrinsically motivated behavior is necessary. With this aspect of motivation in mind, a student's approach/avoidance stance is central (Covington & Mueller, 2001). Here the motives of a student to engage in activity are viewed with respect to the level one displays motivation to approach and/or avoid a task. It might seem illogical to discuss these constructs in an 'and/or' vein until one recognizes an individual could present high or low approach tendencies to activity along with either high or low avoidance behavior. The motives of the student to approach and/or avoid a task inform self-worth theory. Covington's self-worth theory is suggested to mediate the high or low approach/avoidance tendencies of the student since it is the student's personal perceptions of competence which determine their actions (Eccles & Wigfield, 2002). Here exists another transaction between motivation, namely approach/avoidance tendencies, and cognition, an appraisal of personal beliefs of competence, that is goal-driven. My efforts to promote mastery goals take this theory into consideration.

Emotions

The previous discussion implied emotional connections to the transactions between cognition and motivation openly in one case and implicitly in others. The nature of the connections allowing for the transactions between the three constructs suggests it is intricately woven; therefore, separating one facet of the three when discussing transactions between the other two is unnatural and sure to lead to the inclusion of the third in some form. In order to remedy this exclusion I present a portion of the theory of emotion, in general, to lead into my thoughts related to the interplay between emotional experience, motives, and cognition and point to the researchers who have informed my position.

When the Greeks conceptualized reason and emotion as master and slave, the stage was set for feelings to function in a subsidiary role to the more highly valued processes of rational thought. Solomon (2000) traced the historical development of the philosophical thinking of emotion. Reason as the preferred method of behavior dominated as exploring the emotional aspect of action took a backseat to logic and science. Solomon offered several questions about emotion from a philosophical stance. Of particular import is the question, “How should we think about emotion?” (Solomon, 2000, p. 9). This question presents many avenues from which to approach offering a response. I focus attention to two of these directions. First, I attend to the facet of Solomon’s question to deal with discrete emotions as a way to understand emotional behavior in order to further the field of study beyond the limitations inherent to a dimensional theory of emotion. Second, because I believe cognition and emotion are tightly woven, I place emphasis on the perspective relevant to cognition's role in emotional experience. Lastly the interplay between cognition and emotion will be used to explore the transactions between emotional experience, cognition and motives.

The consideration of emotions as discrete or dimensional constructs suggests an avenue to describe what we are thinking about with respect to emotion. Historically, psychologists investigated emotion from the theoretical stance of the dimensional aspects of the emotion (Izard & Ackerman, 2000). Wundt purported the dimensions pleasantness-unpleasantness, relaxation-tension and calm-excitement could be used to describe all emotional responses (Izard & Ackerman, 2000). This line of inquiry gave attention to the positive and negative emotions as well as their duration. With the onset of the 1980's the emphasis on dimensional analyses of emotions eased and discrete emotions theories were starting to have an impact on researchers and the theories they chose to inform their investigations of emotion. This shift to discrete emotion theories carries implicitly the belief that emotions constitute the motivational and cognitive processes of the individual and different emotions carry out this process differently (Izard & Ackerman, 2000). One may use the discrete emotions to consider the role of an individual's anger, shame, joy, excitement, or other emotion on the actions of the individual experiencing a researcher-chosen emotion. The number of discrete emotions differs between researchers, but the actual number is less important than the role of the particular emotion in the actions of the individual.

Using discrete emotions theory allows an educational researcher to focus on a variety of questions. For example, Turner et al. (2002) studied the consequences shame may have on a student's academic failure. Another researcher could choose to describe the impact interest in an aspect of the curriculum has on the student's motivation for a task and the subsequent knowledge developed about the content. I believe the use of discrete emotion theory can offer greater insight into a student's experience with school mathematics also. Currently research in mathematics education rarely considers discrete emotions, save anxiety. Therefore, there is not a strong theoretical basis from which to choose a particular emotion to study. Hence this study will make use of the macro level of analysis afforded the dimensional emotional theories. Ideally situations will arise where gaining deeper understanding of one's actions related to a specific situation or problem to further applications of discrete emotion theory to mathematics education.

Given the strong favor enjoyed by cognition in psychological research, the belief that emotional behavior is dependent on cognition is commonly held. Those subscribing to such a belief tend to think about emotions as being about 'something.' Whether that something is actual or imagined, a cognitive representation of the experience is associated with the emotion because one must have thoughts about the concept or object in question in order to feel an emotion. For instance, it is supposed by appraisal theorists the cognitive processes involved in making an appraisal of a situation are essential for the person's emotional state (Lazarus, 1991). Thus the functionality of emotion is forever dependent on the thinking of the human. From another perspective held by some psychologists, emotion can operate independently of cognitive processes. The automatic responses of the human, in general, to a variety of external stimuli lead researchers to theorize that emotions provide the impetus for these responses (Zajonc & Markus, 1984). Each camp presents empirical evidence of their claim, and I suspect debates such as that publicized between Zajonc and Lazarus could continue (Lazarus, 1984; Zajonc, 1984).

A mediating factor between the theories has been the defining of constructs. The specificity or opposing breadth creates conceptual mismatches to produce this dichotomy

(Lazarus, 1984). I find myself situated between the two camps. I can accept the empirical validity of the findings suggesting emotion occurs independently of cognition in some circumstances while at other times the emotional response is dependent upon the efforts of the mind. Because I pose research questions set in schools, I limit the range of settings where emotional responses may be produced. I further narrow the set of experiences to be investigated given a student must be engaged with a problem for the questions to apply. Thus, I view emotions as products of cognitive processes. The physiological responses observed in connection with one's experience of emotion can certainly be used as an alert, but they are dependent on the cognition of the individual. Because the student's emotional experience was originally due to the evaluations they made of the task, appraisal theory links cognition and emotions (Lazarus, 1991).

I asserted cognition influences emotional experience in a classroom, but the above theorizing expressed no suggestion of a reciprocation of the interaction. I would be remiss to exclude the role of emotions in one's thinking and actions. The correlations to a student feeling positive emotions and thereby experiencing more productive cognitive processes are considerable. Creative and flexible problem solving and other thinking skills are associated with positive feelings. Along with improved thinking skills, positive emotion is also related to increased intrinsic motivation (Isen, 2000). This motivational connection may be highlighted by focusing on flow and the theoretical stance posited by optimal experience (Csikszentmihalyi & Csikszentmihalyi, 1988). This construct can be used to investigate cognition, motives, and emotional experience of a student while engaged with a problem. When a student experiences flow, every aspect of the situation is favorable and task-focused. The three constructs each support and further the functioning of the other.

The transactions between a student’s cognition, emotional experience and motives have been described as quality of experience (Schiefele & Csikszentmihalyi, 1995). Csikszentmihalyi (1988) implied a link to the framing of cognition informing this study, namely the processes of cognition occur as conscious activity as well as operate in the unconscious. Thus occasions where a student experiences flow offer another transactive connection between emotion, motivation, and cognition.

Again goals can be theorized to mediate the transactions between constructs. The appraisals that occur when one is first presented an academic task are goal-driven (Lazarus, 1991). The regulation of one’s motives to remain engaged with a problem, which I view as a series of during-task, real-time appraisals, are also understood as goal driven (Cantor & Fleeson, 1991). Csikszentmihalyi (1988) stated flow connected directly to goals. Thus a student’s goals are an essential feature to understand in order to more fully interpret the transactions between a student’s emotional experience, motives, and cognition.

The affective domain as integrating the transactions

Having struggled to find a description of the affective domain with which I was satisfied, I take this opportunity to explicate my current thinking about the affective domain and its processes as I endeavor to bring some focus and closure to the discussion. In my experience with the literature this work encompasses, I have gained insight into the characterizations of affect of a variety of social researchers. There seem to be common aspects of the interpretations but yet aspects from various definitions that do not seem to fit with my thoughts force me to ponder my interpretation. For example, from the stance of the psychologist, affect is specialized. “It involves evaluations that may have no cognitive basis. … Emotions can therefore be viewed as processes that include affect” (Frijda, 2000, p. 63). In general, this may be true, but the narrow slice of human activity on which I have chosen to focus and the associated transactions between constructs does not connect with this notion. From the perspective of some educational psychologists, affect is characterized as emotions and moods (Linnenbrink & Pintrich, 2003). I suggest that cognition is an aspect of affect and thus refine the definitional process.

The necessity of incorporating cognition in the description of affect is grounded in the work of mathematics education researchers investigating the role of student affect in mathematical problem solving. The characterization offered by Hart (1989) that described the affective domain as beliefs, attitudes, and emotions incorporated cognition. McLeod (1992) discussed the interaction of one's thinking and feeling as affect transacted from beliefs, to attitudes, and then to emotion. He theorized that the role of cognition decreased while the role of the feelings grew more prominent as the individual experienced interactions along this path. This notion of affect certainly is more relevant to this study since mathematical problem solving is a given for Hart's and McLeod's definitional efforts.

I desire a theoretical description of affect, however, that includes an action component since my epistemological stance implies the necessity for action to occur for one to come to know. Because affect plays a large role in my belief, it is important that my description of the affective domain incorporate action. From the previous discussion of transactions among emotions, motives, and cognition, I conclude that one's goals have a major role in the transactions between constructs. Striving towards these goals would offer the action component I seek. Turner and her colleagues (2002) discussed the ideas of several emotions theorists who suggest just such a model. They pointed to Emmons's work and the suggestion that goal-directed efforts are directly linked to affect. In referring to other emotion theorists' perspectives, Turner and her associates described affect as the primary system in which cognition, decision, and action interact and the interaction is continuously interwoven (Turner et al., 2002). It is with these ideas in mind that I offer the conceptualization of affect informing this study.

Since cognition, motives, and certainly emotions are conceptualized to operate within the affective domain, I claim the transactions between these constructs occur within the affective domain, further affective experience can be thought of as the transactions between these constructs. The classic divisions between cognition and affect still exist, but when investigating a student's affective experience it is necessary to consider emotions, motives, and the cognition that occurs in order for the transactions to occur as a student experiences school mathematics. Thus for the investigation of the questions I posed, student affective experience during mathematical problem solving is comprised of the transactions between emotions, motives, and cognition.

Affect with respect to mathematical problem solving

Affect has received far less attention in the realm of mathematical problem solving than cognition. The difficulty inherent in studying affect contributes to the absence. Additionally, progress has been limited by an inconsistent description of the affective domain (Hart, 1989).

McLeod, a leader in studying student affect and its role in mathematical problem solving, pointed to the work of Mandler to draw connections between the cognitive and affective aspects of problem solving (McLeod, 1992). Mandler suggested a student's emotional responses to problem-solving actions are the trigger for many of the related affective factors. Although the emotional response generally lasts a short time, a series of similarly interpreted emotional responses given the same conditions lead to the development of one's situation-specific attitude. Thus, the emotions experienced during mathematical problem solving lead to the attitude one holds for the activity (Mandler, 1989). Literature describes three aspects of affect's connection with mathematical problem solving. First, the beliefs a student holds about mathematics, about oneself as a learner, and about the context of the problem have an important function. The emotional responses to problem solving will undoubtedly operate in the production of the affect. Finally, as multiple situations are encountered with similar emotional reactions, one's attitudes about mathematical problem solving will begin to be developed, thus completing the triad of affective constructs considered most widely (McLeod, 1992).

Characterizations of affect were furthered, extending the work of McLeod, to include values (DeBellis & Goldin (1997)). Interactions occurred between all combinations of the four constructs, beliefs; attitudes; emotions; and values, morals and ethics. This fourth component was conceptualized as the motivator of the system. The inclusion of values in the model of affect and the centrality of one's values relationships to goals aligns the frame offered by DeBellis and Goldin with the conceptualization of affect as the transactions between motives, emotional experience, and cognition.

Mathematical Play and Affective Experience

While exploring literature regarding ideal characteristics of mathematics classrooms, the construct, mathematical play, surfaced. Literature relevant to this construct pointed to researchers investigations of children's play, claiming it is supportive of the development of valuable cognitive, affective, and social characteristics (Bruner, 1976; Piaget, 1976a, 1976b; Vygotsky, 1976). Often, I sense people feel play is not potentially productive and should only be engaged in after one has attended to the serious business at hand. Such a belief is particularly troubling when it is imposed on students. Commonly in schools, students are coerced to engage in activities of 'work' by dangling the reward of 'playtime' for when their task is completed. Thus the students in the class I study will be faced with another transition. As I attempt to choose problems that instill a rewarding, playful aspect to the 'serious work' of learning mathematics, students will have to find a way to understand what to do in such a situation.

Play

To more adequately describe the defining characteristics of mathematical play informing this study, I purport that it is necessary to first describe play. The literature concerning aspects of this construct is quite broad, but focuses mainly on the play activities of the youngest children. The students described are elementary school aged or younger. One reason for such a focus may be due to the work of scholars who are informed by Piaget's thoughts regarding play. Piaget placed strong emphasis on the value of play during childhood for the subsequent learning processes of the individual. He offered description of play by stating, "In a word, it is possible to reduce play to pleasure-seeking, but with the proviso that the pursuit of pleasure is conceived as subordinated to the assimilation of reality to the ego. Ludic pleasure then becomes the affective expression of this assimilation" (Piaget, 1951).

For Piaget, as children began to assume a place in and adapt to the rules of society, their play takes on the rule-guided attributes of adult play and does not represent a vital function of the mind of the adolescent. Although there is still the opportunity for intellectual or sensory-motor fulfillment, these pleasures are only made legitimate by the games' rules (Piaget, 1976b). Additionally with respect to a school setting, as students grow older and adapt to the structure of schools their opportunities to play in the Piagetian sense seem to be diminished

This description of play, namely being bound by a system of rules, could be engendered by activities in mathematics classes where mathematics operated as the confining system. Using Piaget's (1951) characterization of three stages of play, sensory-motor, symbolic, and games with rules and the belief that rule bound play was most beneficial when a person was in control of the rule making, play in mathematics could be used to allow students to develop the rules and learn significant mathematics. Although rule-bound play may not be as productive for a person's global cognitive development as the play activities of the infant, it could support a learner's cognitive development within the context shaped by the rules. Thus envisioning mathematics as a system of rules to support activities in mathematics classes being engaged in playfully is key to the conceptualization of mathematical play informing this study. To further validate the value of play, mathematical play particularly, I offer relevant literature from other sources.

Play has been described to promote convergent problem solving, divergent thinking, and socialization skills (Hughes, 2003). A further link from play to cognitive style has been offered by Saracho (2003) who discussed field dependence independence (FDI) as one aspect of cognition and the differing play tendencies of children respective of these descriptors. Lastly according to the conference presentations of Dockett (2000) and Jones, Dockett, Westcott and Perry (2000) that are cited by Lillemyr (2003) play can be an avenue to refine understanding as well as to generate new understandings.

Play was characterized by Davis (1996) as not the activity itself but rather the willingness to operate amongst uncertainty. He offered that play is not the abandonment of order and comprehensibility, but rather play leads to these ends while it provides a space to support such learning. Since Davis writes with the intent of discussing mathematics teaching, his work regarding play is important for the description of mathematical play I use. It should be added that he playfully dances around ever penning an explicit definition of play, but instead revels in his assertion that play is too playful to allow itself to be defined concisely (Davis, 1996). Another characterization of play is seen in the work of Sylva, Bruner, & Genova (1976) where they described five characteristics of play. These were:

- Practice assembling aspects of behavior into unusual sequences
- Lessens the risk of failure
- An emphasis of process over product that allows the player to view obstacles to a problem-solving opportunity with composure or even glee rather than frustration
- The invitation to notice what may seem to be irrelevant details due to the occasion to consider a wide variety of possibilities inherent to items or events
- The nature of play is voluntary and self initiated.

Here play can be interpreted to have benefits for a student's affective and cognitive development.

Researchers have investigated the connections between a student's cognitive and affective experience while playing. For example, Tamis-LeMonda and Bornstein (1993), who considered representation and symbolism in play activities, found that by assessing the duration and level of play they were able to connect the cognitive-representational frame of the player to motivation and goal directedness. Also drawing connections between affect and cognition by studying play and a student's focused attention during these acts, Ruff and Saltarelli (1993) described patterns in their results linking play to productive affect and learning. Other researchers (Fink, 1976; Hartshorn & Brantley, 1973) described studies that involved control group tests to determine if play opportunities had an impact on cognitive abilities. These researchers stated students who were given opportunities for play performed at higher levels than did those who did not have the play experiences. Not surprisingly given when the studies were conducted, they did not draw connections to student affect. Although the work cited above does not rely solely on data collected from mathematics classes, it can be utilized to aid the understanding of what play can be in school mathematics. Thus narrowing play to mathematical play in particular is discussed in the following section.

Mathematical Play

Not too surprisingly the literature base concerning mathematical play specifically is relatively sparse. This construct has not enjoyed much attention because many perceive mathematics to only be a discipline of serious study. The authors of the *Principles and Standards for School Mathematics* (NCTM, 2000) offer their vision for an idealized school mathematics. In this work they explicitly mention play. When discussing the mathematics for pre-K to second grade students the authors stated,

> Adults can foster children's mathematical development by providing environments rich in language, where thinking is encouraged, uniqueness is valued, and exploration is supported. Play is children's work. Adults support young children's diligence and mathematical development when they direct attention to the mathematics children use in their play, challenge them to solve problems, and encourage their persistence (2000, p. 74).

Although this passage was in the section aimed at the youngest school-aged children, it does not close off the possibility that play would be valuable for others in school. Certainly an eighth grader is quite different in a variety of respects from a first grader, but these differences do not imply the older student cannot play. It only means the play will be inherently different.

Davis (1996) claimed mathematical play has been considered, but simply undervalued. Regardless of the reasoning and beliefs held by people precluding them from thinking of mathematics as an activity that may be approached playfully, scholars have offered their perspectives on mathematical play and conducted research to investigate the effect of play on mathematical learning. Steffe and Wiegel (1994) offer one conceptualization of mathematical play. They stated that their analysis of data gathered in support of the Fractions Project yielded instances of mathematical play. These occasions were observed in the computer microworld designed for the project (Steffe & Wiegel, 1994). Students were given the opportunity to explore the functioning of the computer in a playful fashion. Having created elaborate designs, the teacher, who witnessed the play of the two children, interjected with a question of a mathematical nature. This transformed the play into a mathematical activity. The question posed by the teacher evolved into independent student actions. It is this transition to a student's independent activity where mathematical play began (Steffe & Wiegel, 1994).

Holton and his colleagues (2001) also described mathematical play. They suggested mathematical play is an aspect of the process of solving mathematics problems including the generation of ideas through creativity and experimentation within the constraints of the formal rules of mathematics. This characterization resonates with Piaget's rule-based games alluded to earlier. Holton et al. also described mathematical play as offering a safe environment where incorrect solutions are not mistakes, but rather may promote better understanding of the problem or other mathematical misconceptions (Holton et al., 2001). An essential aspect of mathematical play each group of mathematics educators has offered is the child is in control of the playful activity. This control can be viewed as one contributor to positive student affect.

If mathematics classes incorporated opportunities for mathematical play could we expect students would learn more? Some research suggests, in fact, mathematical play does foster improved learning. Zammarelli & Bolton (1977) studied 24 children ten to twelve years old. One group was allowed to play with a toy that mimicked mod 4 arithmetic. A second group was allowed to watch the students play, but not play themselves. The third group had no experience with the toy. Each student was then given a task to assess the level at which they conceptualized the activity. There were no significant differences in the scores on the task prior to playing with the toy, but after the opportunity for mathematical play, the players did significantly better than either other group. As a second example, Rogers and Miller (1984) gave first year secondary school students a pre-test on factors and multiples. The students then played an active game and retook the test with vast improvements. Of particular interest is next the researchers chose the three weakest students and gave them the opportunity to teach and play the game to a group of younger students. A retention test was given shortly thereafter and these three weakest performers far surpassed the others, a group given a reminder session in a lecture format and a group given no additional instruction. These two studies suggest that mathematical play promoted learning.

Not surprisingly other connections between mathematical play and learning are described as promoting productive affective experience. Building on an aspect of Holton et al's characterization of play, the opportunity to engage with the mathematics in a safe environment, offers potential to influence the affect of the learner. Being allowed the opportunity to delve into a particular problem without the fear of being determined incorrect and the potential consequences of this error, will allow the learner to experience thought processes that may not have occurred previously. This thinking not only has the potential to improve the understanding of mathematics, and a student's affect.

Henniger (1987) supported the view that play in mathematics and science classes promoted the development of positive attitudes in the learners involved. He postulated the process-oriented nature of mathematical play could support a student's self-confidence and motivate future play since the activity was chosen by the student and had a low likelihood of producing incorrect responses or embarrassment. Lastly, curiosity, which can be linked to learning and affective experience, is promoted by activities where children can engage in mathematical play (Henniger, 1987). Dienes (1963) also suggested mathematical rule-bound play has a productive influence on student affect. Hence, mathematical play can be realized as promoting student cognition as well as productive affective experience.

Connecting mathematical play to Polya

I next relate mathematical play to the tasks of school mathematics. First, it is essential the student engage in a process that is unfamiliar. This original mathematical activity is for my purposes problem solving as described earlier (Polya 1957, 1962). The requisite condition necessitating a student engage with a problem in order for mathematical play to occur is coincident with the characterizations informing this study (Davis, 1996; Holton *et al.*, 2001).

It is with Polya's (1957) four phases of problem solving I frame mathematical play. These phases, understanding the problem, devising a plan, carrying out the plan, and looking back to examine the plan and the solution allow for the connections between a student's engagement and the aspects of defining mathematical play described. I envision mathematical play as occurring primarily during phases 1, 2, and 4. It is during these phases that students undertake the process of generating ideas with their creative powers. Since mathematical play requires activity take place within the rules of mathematics, understanding the problem may be approached playfully if a student attempts to connect the given information and the condition by searching for a relationship in a way that is pleasant for activity. Similarly, when a student is confronted with a problem, play may be incorporated in the process of devising a plan. If connections between given and condition are determined the student engages in activity to further understand these connections and potential others in a fashion deemed interesting, a plan to determine the unknown may arise from this playful activity. Once a plan is devised and the student begins to carry out the plan, play subsides as the 'product' of the activity moves to the forefront of the student's efforts. A student could operate within aspects of the plan playfully, but in this case I claim this activity would be motivated by a different problem, namely how to find enjoyment in carrying out the plan.

If it becomes apparent that the devised plan is not a fruitful one, then play may resume as the 'process' of problem solving returns to the forefront of a student's action to devise a new plan or try to understand the problem more deeply. Finally, having arrived at a solution, if a student engaged in Polya's looking back phase, mathematical play may again fuel a student's actions in an effort to relate the new knowledge to other problems or in a search for other solution methods. As a student tried to address a 'what if' question during this phase, activity could be playful if the student's engagement coincided with the described aspects of play. Thus, I will use the phases of problem solving to more fully characterize mathematical play and students' problem solving engagement for this study.

Supporting mathematical play in school mathematics

In order to bring mathematical play into school mathematics it is essential to make some connections between the theoretical ideas and the practical requirements of schools. First, incorporating mathematical play into school mathematics requires support from the school community. For example NCTM (2000) stated,

> "schools should furnish materials that allow students to continue to learn mathematics through counting, measuring, constructing with blocks and clay, playing games and doing puzzles, listening to stories, and engaging in dramatic play, music, and art" (2000, p. 76)

I believe mathematical play should occur in more of these activities than just 'playing games'. In fact, each of these activities has potential to promote the mathematical play of students. Further NCTM pointed to a need to allow students to explore mathematical phenomena. This objective can be addressed in a number of ways. One is for the teacher to tell the student what to explore, thus foiling an opportunity for mathematical play to occur. The suggestion of the Council is to provide a rich context with which a student has interest but little experience. By engaging a student's curiosity in the mathematics of the context, mathematical play can be promoted and learning enhanced. This action can in turn contribute to the exploration of a particular avenue toward a solution of a problem. Thus the exploration that NCTM called for can be fostered by mathematical play.

To support mathematical play in school mathematics requires more than materials and a mathematical phenomena to explore. Particularly it is important that the role of the teacher be considered since it is the teacher who is most essential for the integration of play and school mathematics. Lillemyr (2003) discussed research from various countries and stated that commonly teachers saw their role as observer with little participation beyond offering scaffolding, which was suggested to support student play (Holton et al, 2001). By offering evidence play was more valuable for the learning of the student when an adult was involved, Lillemyr built a case to consider the teacher's perception of what play is when attempting to draw connections between theory and practice. The impetus for his discussion was the curriculum changes recently undertaken in Norway. In order to promote intrinsic motivation and self worth the reformed curriculum (Reform 97) places an emphasis on play "to an extent that is probably unique in Western countries today" (Lillemyr, 2003, p. 56).

Although it could be assumed that studying teachers' perceptions of play in Norwegian schools would provide a unique perspective into the role that a teacher would take to promote such activity, Lillemyr cited several studies making claims that teachers tended to be supportive rather than interactive with their students while playing. Given curricula are placing greater curricular emphasis on play and the research evidence that primary school teachers in these nations are unsure of their role in promoting play, Lillemyr offered ten possible elements of this role. A sample includes:

- Developing competence in guiding, supporting, and involving himself/herself in children's play, *while providing them opportunities for choice (from another one that I excluded)*
- Discussing the value of play in the school curriculum with colleagues,
- Promoting positive interpersonal relations in the classroom, based on a "supportive teacher attitude",
- Showing engagement with students and their self worth (Lillemyr, 2003, p.68).

Thereby, a framing for the consideration of a teacher's role in promoting play activities gained needed improvement.

Teacher/researcher & student transition

Concluding the discussion of the literature informing this study, I briefly point to two areas relevant to the study that I have not explored. I have read very little about what it means to be a teacher researcher. Various works of Lampert and Ball have impacted me in which each discussed research conducted to more fully understand student learning as well as their teaching practices. I do, however, approach the study I pose with the intention of taking advantage of my previous experience as a teacher of middle grades mathematics. Further as the teacher of the class where the study is being conducted, I have in-depth access to a variety of understandings that are important for an educational researcher. For instance, simply by being in the classroom on a daily basis made my study of student mathematical play less contrived than if I had only been present in the classroom once or twice a week. Secondly, since I was present each day and conducted professional development with the mathematics teachers for a year and a half, I had the chance to gain greater understanding of student knowledge and the particular socio-historical contexts in which the students operated. This information aided my ability to draw inferences from student actions.

The second limited area in my exploration is the literature of transition from one form of school mathematics context to another. The literature is sparse at best. Scholars study the broad transition from one level of schooling to another. Others have explored the transitions that exist in mathematics classes as a student moves from the elementary school to the middle school (Di Cintio, 1996; Midgley *et al.*, 1989). The specific transition of pedagogies I attended to while investigating my students' experience seemed not to be documented in scholarly literature. Thus by investigating mathematical play, how technology might support student play, and attending to the transitions students experience, this study has potential to address several gaps in the literature of mathematics education.

CHAPTER 3

Methodology

In choosing the techniques used to investigate the questions posed, the methods necessarily must be useful to address the questions. My questions and epistemological stance are supported by the development of a case study, for each student chosen as a participant, interpreting experiences while using technology tools and engaging with specific problems. These cases are informed by students' experiences with problems throughout the course, the ways students incorporate technology tools into their activity, and their affective experiences. Because a transition in pedagogies is critical to the student's experiences with school mathematics during this study, socio-historical aspects of the school, the district, and the mathematics teachers are also worthy of attention.

To further refine my methodology, I explored the methods of others investigating aspects of affective experience. Recent work of educational psychologists who described changes of methodology as well as theoretical considerations in order to advance the study of emotion, motivation, and cognition is offered. Making use of the theoretical discussions that have informed the investigation of related questions, I describe the methods used in this study.

Given the historical dichotomy of cognition and emotion, inquiry into student activity has paid little attention to emotional experience of the learner. With the exception of Weiner's research investigating attributions on academic emotions, the only emotion which has been researched extensively is test anxiety (Pekrun *et al.*, 2002). The omission of emotion from programs of educational researcher is beginning to be corrected. Meyer & Turner (2002) in reflecting on their last decade of investigation of student motivation describe the 'serendipity' of discovering emotion as an integral facet of the interactions of students and their teachers. These researchers suggest the three components of human learning, cognition, motivation, and emotion, which have historically been studied separately, should be conceptualized as one system. Turner, et al. (2002) echo the stance that future inquiry into the interconnections of these constructs in an academic environment is essential. By focusing on the discrete emotion, shame, these researchers offer empirical findings about affect. Although they have been able to provide new evidence of their theoretical stance, the field can progress much farther. In their discussion of advancing the field, Schutz and DeCuir (2002) offer methodological considerations for the study of emotions. The stance that differing methods of inquiry are beneficial to the field at present leads to the proposition to consider poststructural methods and deconstruct the definitions of the current interacting constructs. Also, the inclusion of multiple methods in the study of emotions in education is conjectured to supply another avenue to gain new perspectives about these phenomena (Schutz & DeCuir, 2002). Those researchers focused more toward the study of motivation in educational contexts are also using new strategies to explore the interplay between motivation and a variety of other constructs. A critique of prior methodologies and several developing methods are described next.

Beginning several decades ago achievement motivation was investigated with cognitive models. More recently motivation researchers are beginning to adapt multi-construct models that describe the interactions of a variety of constructs (Jacobs & Osgood, 2002). This developing methodology is due in large part to the limiting aspects of prior methods. For example until the 1990's most instruments used to study motivation were questionnaires administered to students only once. In essence these questionnaires required the student to assume context from which to respond to the items. As the notion that motivation is domain-specific rather than a generalized trait became more widely accepted, these instruments were adapted to pose questions relevant to a particular content (Boekaerts, 2002). These methods of assessment still fell short when the dynamic between the learner and the particular socio-historical context was valued as a construct to be understood (Jarvela *et al.*, 2002). In response to this exclusion, new dynamic theories of assessing motivation while the activity is occurring are coming into the forefront of the field (Ainley & Hidi, 2002; Boekaerts, 2002; Jarvela et al., 2002). The methods these researchers make use of allow students to offer analysis of their affective experience as they engage with an academic task. Endeavoring to describe the motivation of a student during activity provides the opportunity to investigate how aspects of the activity as well as one's feelings and thoughts regarding the task impact the action of the individual towards the goal. These new dynamic methods along with the more commonly used questionnaires can be incorporated in a multiple methods approach in order to describe particular interactions of an individual given the context as well as general characteristics of groups of learners. I intend to incorporate quantifiable measures similar to those described above into the data collection aspect of this study.

Using directions in which current research into student motivation and emotion are growing supports the investigation of transactions between emotions, motives, and cognition. Assuming a researcher accepts the complexity and dynamic nature of the transactions among affective constructs (Op 't Eynde & De Corte, 2002), then choosing a construct from which to frame the observation and learn how the transactions between one's thinking and feeling occur is important to make such a research task manageable. Because schools are fundamentally set up to develop the thinking of the students and cognition has enjoyed the lion's share of researcher's attention, I focus this investigation by analyzing the role of students' emotional experience with school mathematics. Further attending to students' emotional experience is productive for efforts to support an interpretation of students' engagement with course activity as playful or not since play corresponds with different emotional experience than non-ludic activity.

The guiding principles informing efforts to investigate the questions posed were not all incorporated. No quantifiable items were administered to students. The absence of quantitative instrumentation to gain information from the students is due in large part to the inability to select constructs to be examined by such tools. Because the investigation of the questions posed is not widely documented in scholarly literature, one purpose of future analysis will be to identify constructs integral to student's experience and thus warranting further quantitative investigation. Data was gathered and analyzed, however, with a focus on student emotional experiences with school mathematics. Before describing particular procedures used to gather data, I first describe the requisite planning of the course.

Epistemology Driving Pedagogy

Planning the course within which this study was conducted, derived from my epistemological stance. Thus, the activities of the course were designed to stimulate the thinking of the student rather than simply provide an opportunity for students to apply a newly learned procedure. Because I believe students do not develop a deep knowledge of mathematics by mimicry, but rather by doing mathematics, students were given the chance to engage in original mathematical activity.

Further I drew connections between my planning of the course and the framework Schoenfeld (1992) described to analyze the problem-solving activities of students. The fifth component of Schoenfeld's framework, practices, requires a description of the environment and the epistemological stance of the teacher. I view this aspect of the framework as the component in which a teacher has the greatest influence on a student's experience with school mathematics.

Hopefully all members of the class added to their knowledge base while engaged in mathematical activity. A teacher can have a role in this development. Students also had the opportunity to develop and use strategies to solve problems and again a teacher can have a role in a student's development of strategies. A metacognitive adolescent may monitor experience while solving problems and have a way to enact control in order to continue in a productive fashion. This form of student enacted control is indicative of goals. A teacher may have an impact in changing a student's ability to monitor and control the experience. Likewise a student's beliefs about school mathematics can be altered by a teacher, but like the three prior components of the framework, a teacher cannot influence this aspect of the framework to such a degree as practices. Although the transition from one course to the next likely affected the first four components of the framework, the practices component had the greatest impact in a student's efforts to transition. Hence it is important to explicate the epistemological stance that informed decisions for planning and carrying out such plans in a middle grades mathematics class.

Because I believe a student must engage in mathematical activity in order to learn mathematics, students had opportunities to explore problematic situations. While engaged in problem solving, I desired students determine their own strategies to move towards a solution. Then, I wanted students to use these strategies, arrive at a solution and be able to use mathematical reasoning to support the determined solution. Building on my knowledge of the students' prior experiences with mathematics in school, I was assured my epistemological grounding will necessitate that students in this course will need to make sense of a different set of practices. Where students previously carried out a described procedure to arrive at an answer for a teacher's question and then received acknowledgment from the teacher regarding the correctness of the determined answer, in this course students experienced different practices.

Because I ascribe to the philosophy that an individual must experience some form of disequilibrium in order to assimilate experiences to prior schema or make accommodations in the knowledge structure it becomes necessary to provoke perturbations for students. These perturbations occurred relative to the mathematics of the problems the class explored and also with respect to the transition from one set of practices to another. When students struggled to resolve an experienced disequilibrium, be it with mathematics or practice, I did not simply tell them what they needed to know. My epistemological stance leading me to not act in the way students expected, and thus created a *larger* transition the students had to endure. I made this choice and realized it necessarily impacts the practices of students' activity. From my prior work with students both in this school and others, I have compiled evidence supporting my thinking regarding a student's desire to be told what to do or if their thinking is correct. Many students expect a teacher to answer a student's questions directly, to tell them what to do, and to act as the knowledgeable other and give validity to answers the student's offer. These student expectations would rarely be met in our course.

The use of technology tools had a strong influence on the practices component of the framework. Given that these students had little experience using technology tools to engage in mathematical problem solving, the inclusion of another alteration of practice influenced the character of students' mathematical activity and their transitions. Although I grant that using technology tools is likely to influence one's knowledge base and strategy use, these components of the framework will only be affected when the student finds a way to incorporate the tools into their activity. Also, the use of these tools will influence a student's affective experience, but again the trajectory of such an interaction is contingent on practice.

My efforts to analyze a student's mathematical play and its connections to the incorporation of technology tools is also linked to my epistemological stance and Schoenfeld's framework. Again the primary connection for me lies with the practices component. Within this component, practice, the student is provided an opportunity for mathematical play. This activity can then in turn affect each of the other aspects of the framework. Theoretically while playing mathematically, a student learns new mathematics and thus adds to the knowledge base. While playing, a student also explores and experiments with new strategies that may prove to be useful or generally unproductive. If one accepts that while engaged in play a student experiences flow, then it follows that the student gains ability to monitor and control the activity. A student's affect is also impacted by the practice of playing mathematically. While a student plays, affect is theorized to be approaching an optimum trajectory. Emotional experience is productive for the student's motivation and engagement with activity. Thus in planning a course where students have opportunities to play mathematically, the perturbations provoked by mathematics or pedagogy may be assuaged and potentially resolved.

Keeping Up with the Course

To create a course where both the questions posed could be investigated and the mathematics education of the students could be furthered along the path anticipated by state standards, district personnel and the students' caregivers, I identified big ideas from which the particulars of the course would be shaped. These big ideas consisted of number theoretic relationships, ratio and proportion, and geometric topics. I considered some potential mathematics problems but did not have a regimented set I planned to use. With the intention of integrating other aspects of mathematics content into discussions of these topics I began the year.

My role as the teacher of the class necessitated I remain flexible in my planning as I assessed my students understanding to determine what sorts of tasks would be most appropriate. On the occasions when our progress with a given problem had reached a standstill, I worked to support students thinking by helping them to understand the conceptual ideas relevant to the given problem. This effort required I place students' thinking at the center of the planning and use their developing understanding as the catalyst for my subsequent teacher moves. Often this choice meant the investigation of a problem could go on for days, but having anticipated the potential of such events, I was not concerned when this actually happened. I did, however, on multiple occasions need to ask a question that could support a student's progress. Additionally when the class discussion deviated from a problem in order to discuss the conceptual ideas relevant to the problem, it was critical to find a way back to the problem in such a fashion that the connections between the concepts and the problem were apparent.

Incorporating technology tools

The incorporation of technology tools into a student's experience with school mathematics was another aspect of the transition students confronted. Rather than present scripted projects or distribute 'how to' lists for the software, I planned for the use of technology tools to comprise an element of problem solving. Because students needed a conception of the technology tools they would use, I recognized a need to demonstrate basic aspects of the software with the instructor's computer and projector.

To support the students' efforts to learn about the Geometer's Sketchpad (GSP) and Microsoft Excel some basic features of the software applications were demonstrated. These features included the tool bar and the construct and the transform menus for GSP. With Excel, I demonstrated using the equal symbol to create a formula and how to fill down in order to apply a formula to multiple cells. Naming conventions were described also. Not only did the students need an impression of what aspects of mathematics a given technology tool would facilitate, but also what needed to occur for the tool to be put to effective use. Thus I allowed the software to remain problematic, but I offered an avenue with which students could begin to learn how to use the tools.

Assessment

Having alluded to assessing student progress earlier, I next describe how I made decisions about the grades that students would receive on report cards. Early in the year I assigned grades on homework assignments based on student effort. Using a five point scale, I determined how diligently a student had attempted to engage with each homework assignment. This method had worked sufficiently for me in my past teaching, but I quickly realized a difference. In the past students were expected to try several examples of a procedure that had been demonstrated in class. How many of the exercises one attempted determined the effort grade. Here the situation was different. I was asking students to attempt to extend their own thinking from class. I had not demonstrated a procedure for students to follow on several similar exercises, but instead wanted them to continue exploring a problem posed in class. I decided this form of assessment was not supportive of students for the reasons above and more importantly given the individual differences of students in the class. For the first time as a teacher I positioned myself to assess students based on their own progress relative to what I believed they were capable of rather than compared to other members of the class.

In order to enact this form of assessment I actively pursued the effort to understand what a student knew. I used whole group discussions, small group interactions, one to one exchanges, and students' written work in order to form the most complete opinion I could. This decision coupled with the fact many students struggled to support their solutions with reasoning led me to decide not to give tests. One reason was I would realistically have to create different tests for different groups of students depending on my assessment of their understanding. More importantly for my purposes, however, were the potential ramifications for student motivation. I asked students to think about mathematics that was difficult for them. By adding potentially low scores on tests into the transitional aspects of the course, I feared students would exhibit a tendency to quit trying sooner than they may otherwise.

There were consequences for my assessment decisions. Since I was taking no grades a student was readily aware of, I had included another aspect of practice requiring a transition on the part of the student. Secondly, given I was not returning student papers with numbers written on them but yet students were all getting passing grades on report cards, the tendency of students to not engage with the problems was fostered. Since I believe mastery goals to be a particularly fruitful goal orientation for a student's learning, however, taking away an aspect of the performance of the course had the potential to influence a student's goal trajectory. There was still the performance related goal of not looking foolish in front of one's peers, but an aspect of performance goals were removed given my assessment decisions.

Gathering and Analyzing Data

In order to gain a depth of understanding of a student's experience with the course, I gathered data with a variety of methods. First, I was aware of and collected student artifacts. These included assigned problems to be solved at home, classwork, and paragraphs students were asked to write explaining the mathematics we were studying in their words. Since I was not assigning numerical grades for these student work products, I returned the students work with my written comments included. These comments took the form of praise for good work and questions that I asked when students needed to explain themselves more thoroughly. Often students would respond to these comments in writing and I would gather these items as data. I collected student notes at the end of the year as a form of data as well as the students' end of year projects. My informal conversations as well as periodic semi-structured interviews with central participants were also sources of data. The files central participants saved on the computers in the classroom are a critical source of data that I collected. By gathering all student work into one folder on each classroom computer, I was able to compress the documents and transfer them to my system for data storage. The saved files of central participants comprised a primary source of student engagement with technology while problem solving. An essential source of data was the video recordings created over two months at the beginning of the second semester. This aspect of data collection is described below.

To analyze the experiences a student had solving particular problems with technology tools, a digital video camera was focused on the monitors of central participants as they used the computer and engaged in problem solving. This camera captured a running record of each participant's actions with the computer. A second camera was positioned above and behind the computers with the purpose of recording a central participant's facial expressions and body language. An external microphone was placed on the middle of the three monitors and was intended to capture the utterances of participants (see Image 1). This 'student camera' and microphone were key to gathering data that offered a perspective on students' emotional experience.

QuickTime™ and a
Sorenson Video 3 decompressor
are needed to see this picture.

Image 1: Arrangement of Technology Tools and Video Cameras

After capturing video of the central participants that filled a 90-minute mini DV tape, the video from different class meetings was digitized, compressed, and saved as a QuickTime movie. Since two cameras captured the experience of participants, two movies existed for each instance of technology tool use. Using Final Cut Pro I synched the two movies and imported them into a new file to allow the movies to be played at the same time. This two-in-one QuickTime movie was the form in which video data was analyzed[1]. This data depicting student experience during activity allowed me to interpret the emotional experience of the student and its influence on activity.

In order to analyze the data relevant to my questions I used a multi-leveled interpretative analysis of the colleted videos. I began by first playing the movies in the background as I did other work. I noted occasions I viewed to be important to a student's experience by typing narrative statements about the clip. Data analysis progressed to another level as I began to analyze the student's saved files. Writing descriptions of the student's files allowed for this next level of analysis. Again the videos played as I analyzed the saved files. Further I used the videos captured during the specific times while students produced their saved files to analyze how an

[1] Image 1 is a screen capture from one of the two-in-one movies created from the video camera.

individual’s affective experience influenced engagement. This analysis was carried out with an intensive understanding of the students’ experience in my class as well as with their prior experiences with school mathematics in general. The particular insight I enjoyed is described below.

Prior Role in School Via Professional Development

Having been involved with the mathematics education of the school in particular and the district in a more general sense, I was afforded particular knowledge of the students and research participants. Beginning in November 2004, I had regularly spent time in the school and in particular in the mathematics classes. My experience was primarily as a professional developer working with the mathematics teachers. From these observations I gained an insider’s view of the students.

More importantly to my knowledge of the students for my research purposes is the fact that the teachers each gave me carte blanche to ask the students questions and to try to steer a conversation in a direction focused on conceptual understanding. Thus, I was able to learn how a broad spectrum of the students that had been in mathematics classes of the district thought about mathematics. Some students attempted the conceptual questions. A greater percentage would try in rooms where the classroom teacher seemed to be interested and encouraged the students. More importantly may be the later occasion when the classroom teacher didn’t say it was too hard or it was not right for these kids. One teacher made the comment these kids were not really going to be able to do that, with respect to answering conceptual questions.

As further evidence of students’ thinking about mathematics, I also attended the after school tutorial program, “No Excuses.” Here I was able to interact with the students who had parental permission and an educator recommendation with a sub par standardized achievement measure score to attend this program. This program offered evidence that decisions to teach mathematics for achievement was viewed as a procedural task. Some school employees voiced concerns that the program might not be the best but it maybe could help to support student's work with mathematics. These students showed capacity to think conceptually but few seemed motivated to attend to a particular idea for an extended period of time. Having just attended a full day of school this is not particularly surprising. After the daily program, excluding Friday afternoons, the students were bused home.

Key informants

The strongest avenue into my work with the students in my 04/05 7th grade mathematics class were my key informants I met while engaged in professional development. This group comprised 4 people. Three of these were the grade level mathematics teachers, Beverly, Brian, and Henry. The fourth was the principal of the school, Ms. Putnam.[2] I first met the teachers at the first Institute of the Center for Proficiency in Teaching Mathematics (CPTM). I came to know them as colleagues and over the span of two years I got to know them well. Therefore I had the opportunity to understand more about what they were telling me and had told me as time progressed. The year in which I conducted this study I was again engaged in professional development with Beverly, Brian, and Henry. One of our efforts involved forming a mathematical learning community (MLC). In addition to other content we also discussed aspects of the study and students' responses to problems. I believe that each teacher found value in our

[2] I have chosen the surname and title of the principal to name her in this document because she was the only individual in the building I referred to with a titled surname. I did occasionally refer to Henry with his surname. Most colleagues did use his surname and our age difference seemed to elicit my title use. When Ms. Putnam asked me about my choice to not address her by her first name, I explained I needed to call her that since she was principal.

interactions; although, I question if any one of them took away as much from me as I was able to learn from them.

Beverly

Beverly, a white lady in her 50's, taught 8th grade. She has four children, a daughter in the 6th grade in the middle school and 3 older sons in their 20's. She continues to play softball and coaches the high school softball team and the middle school baseball team. Her Christian faith is very important to her and she regularly had a small 'jam box' playing a Christian, easy-listening radio station in her classroom.

Beverly was trained to be an elementary school teacher. Circumstances being what they are in education she found herself teaching 8th grade mathematics. The level of mathematics that could emerge in an 8th grade class made her apprehensive about posing open questions. She did not hide her feelings that she wanted the 8th graders to attend algebra I classes at the high school. She viewed her mathematics knowledge as insufficient and regularly asked questions to clarify mathematical ideas.

Beverly had spent significant time in the district and offered realistic insights into the lives of the white middle class students in the school. During our MLC meetings, she was routinely surprised by the conclusions students in my classes determined for different problems. I found her impressions of what students could do mathematically to be short of what students could actually achieve. I attribute aspects of this interpretation to be related to her mathematics knowledge.

Henry

Henry was the grandpa. He had met nearly every child in the school when they were in the elementary and primary school. His grandson who was in the 6th grade at the middle school the year of the study, started school near the time Henry retired from his communications technology career. He began volunteering at his grandson's elementary school and shortly was provided a corner with a rocking chair and student chair to work with individuals. It was labeled "Grandpa's corner." Henry, a white man in his 60's, enjoyed being around the children and was motivated to return to school and earn a teaching certificate. Given a love of mathematics and a desire to help students see the applications of mathematical ideas, in what he termed the 'business world,' Henry completed his teaching credentials at nearly the same time I met him.

Henry was the strongest mathematically and eager to think about mathematics in our conversations, with his students and in our MLC meetings. He quickly came to the decision pedagogically to pose tasks for his students so they could learn more mathematics. His awareness of concepts our students could approach with reasonable effort allowed me to bounce ideas off him to get a sense what another thought of my plans.

Henry was very kind to me and wanted me to succeed in my every endeavor. He offered a respectful description of the personal lives of students that I needed more information about in order to work with them more effectively. He was never pushy in this respect and I have no recollection of him ever speaking of a student in an 'oppressive fashion.'

Brian

Brian is a tremendous person. In his early thirties, he is the father of a 4-year-old son and an infant daughter. His wife is a teacher in a nearby district. The only black male academic teacher in the district, Brian grew up in a neighboring county. He could earn more money working in the school district where he and is family live, but Brian continues to travel the extra distance to the district because he feels he has a positive influence on students, particularly those who do not have gender or ethnicity in common with other teachers. He is firm in his Christian faith and made it apparent in his conversations with adults on several occasions. I never observed him using the doctrine of his faith to impress upon a student how they could act in school. He had taught for ten years dividing his focus between mathematics and social studies. He was one of the two teachers working with the No Excuses program. Additionally Brian was doing coursework to earn an online Master's degree in education administration.

Mathematically Brian was stronger than other sixth grade teachers I have worked with. He was willing to engage with problems in our MLC meetings and to explore problems I posed with his students. He would listen with interest as I recounted incidences of my students solving problems. On several occasions he voiced to me these problems were good things to use with the smart kids. I know Brian felt as if he taught to the middle and was doing the brightest students a disservice with such practice.

Brian is hip and with the times. He accepted me as a colleague and friend as evidenced by our greetings and the level of personal information we shared with one another. As key informant this relationship proved very important. I was instantly granted respect from many students simply because Brian and I were viewed as friends. He was pivotal in helping me to understand the black students of the school with greater depth. Additionally, having spent more time with Brian and his students the year preceding the study I know his teaching style the best. This information proved invaluable as I worked to understand my 7th graders during their transition into our class.

Ms. Putnam

Ms. Putnam, a black woman in her 50's, had been the principal of the middle school for 6 years. Her training and previous work in the district regarded labeled students and providing support for their experiences in school. She has 3 children, we talked about them routinely, and a loving relationship with her husband of 2 decades. She had previously worked in a county in the greater metro area of the city nearest the district.

A number of the teachers perceived her as being light on discipline and based their beliefs on the fact that she rarely sent children home on suspension. Of course, she was receiving pressure from her bosses to keep attendance rates as high as possible and thus was caught in a Catch 22. She was aware of the teacher's perceptions, but I believe largely saw it to be for the best interest of the student to be at school and try to improve on inappropriate actions rather than be suspended and out of the building.

I was afforded a genuinely comfortable collegial relationship with Ms. Putnam early in our work together. Upon beginning my work with the mathematics teachers of the school the previous year I routinely stepped into her office to keep her apprised of our work and its progress. She was ever gracious and willing to have me interrupt her day. She also felt comfortable with me. One example of this is seen in our interchange after school during a "No Excuses" celebration for the birthday of the guidance counselor who coordinated the program. Mrs. Putnam and I were off to the edge of the gathering and she was in the process of describing how she perceived the operations of the school, her role in these, and that of the other teachers. I felt the exchange benefited from a familiarity that is not commonly found between colleagues that have spent less than half a year working together, and Ms. Putnam sensed this as well. At one moment she stated, "I have just told you things that I have not told anyone else that works here. How did you get me to do that?' I responded people often told me things that were personal for a variety of reasons but in all cases I keep these exchanges private. She nodded affirmation and continued telling me about her perceptions of the school and the district. This insight proved helpful in my understanding of the school where I was working.

Ms. Putnam was also willing to allow me the leeway to try ideas that I wanted, both with her teachers from a professional development standpoint and with the students at her school regarding my instructional practices and my research agenda. She never once responded negatively to a request of mine.She was supportive in every regard to my face and I suspect when I was not present as well. I believe the latter to be true given that she was willing to be the informant for me to let me know a colleague had voiced concerns about my pedagogy and the students' ability to achieve on the state tests. She confirmed her support for me and my endeavors explaining she wanted me to understand more deeply about the climate of the school.

Brian's pedagogy

Given the nature of students' transitions between differing experiences with school mathematics, careful consideration need be given to students' past experiences in order to understand how aspects of a student's experiences are likely to differ. This understanding also allowed for greater understanding of the extent to which a student's expectations for school mathematics would be different. The professional development work I did at this middle school proved beneficial for this aspect of planning the study.

When in the 5^{th} grade, a large number of the students had a teacher I knew from professional development experiences. She taught at the elementary school, so my time in her classroom was limited. On one visit to her classroom she shared an item of student work with me. It was a single sided page with dozens of exercises. The mathematics of the exercises was of a nature that many educators would describe the exercises as basic facts. Few students had more than 90% correct according to the teacher. Based on other discussions I had with her, conversations with Brian, and statements made by students and parents I can reasonably surmise the mathematical experiences of the students during 5th grade were largely teacher-directed and focused on particular procedures necessary to determine correct solutions.

The students in the class to be studied also were largely in Brian’s mathematics class during the 6th grade. With the previous information offered describing Brian, some aspects of his teaching style can be surmised. He values helping children to obtain a productive education. In his view there are definite things that students should be able to perform competently while in and after leaving his course. Although his students struggle to meet his expectations, he maintains high expectations for what he wants students to accomplish. When a student struggled to address a direct question or to complete a mathematical task, Brian prompts his students for responses by making use of context clues. He never to my observations simply told a student an answer directly. However, often he would tell a student whether a response to a question or an answer to a task was correct.

Knowledge of Brian’s actions in such circumstances alerted me that not telling students when they were correct, but rather forcing them to understand how they arrived at a solution and why they believe that the solution is mathematically sound could likely elicit student perturbation. For the students it would be critical to understand why I require they engage in these different experiences. My prepared thinking about this situation is to build as a major premise of the early part of the class norms that mathematical activity is not simply getting an answer. I expected to support students as they work to understand reasoning can be used to justify the validity of their mathematical assertions. The level to which I stress this component of student experiences was determined by the climate of the class as we progressed through the year.

I also had knowledge of Brian's general interactions with students and the interactions he valued between students in his class. Students in Brian's class were observed working in groups multiple times during any week. These student-student interactions were focused by a task that Brian had given them. At times the groups communicating about other topics might outnumber the groups that focused the majority of their talk on the task. These less-focused groups would return their talk to the task after a few moments. A small percentage of student groups would revert to the activity of the task when Brian would move from interacting with one group to another. This subversive act of the few and the tendency of the majority of those off task to return is evidence of one way all students knew Brian was in charge of class. When the students were having fun in a manner that was acceptable to Brian, then he was happy for them and it was not uncommon for him to engage in the good times with the student(s). When a student acted in a way that was inconsistent with the norms Brian had established, however, he was quick to let that student know he had screwed up in no uncertain terms. Brian's informing the student or group of students that inappropriate actions had occurred could be carried out one on one or in front of any number of a student's or group's peers. To his credit Brian was always consistent and fair in his treatment of the students.

This knowledge of what the students in my study had experienced was important to my planning from a perspective of developing mathematical community. Because students had previously experienced Brian's methods to let them know when they were acting inappropriately, I knew my tendency to be direct and loud when a student was acting against the norms established for the class would align with a reasonable proximity to their expectations and prior experiences. Additionally by observing the student-student interactions in Brian's classroom, I gained information to inform the planning of the course. In particular, the students worked more effectively in small groups and when each group was closely observed without large periods of time passing. This need to move quickly between groups presented an issue to attend to when deciding how long to let a group work on their own and what sorts of support a student may require to further his efforts.

Choosing central participants

Because the theoretical framework informing this study emphasizes the individual's thoughts and feelings more than the group's, I chose four students as central participants of the study. These four students are referred to as the participants in the remainder of the document although all students participated in my research. The role of the participants was critical to my efforts to understand how the transition to a problem-based classroom impacts a student's affective experience. Additionally their activity with technology tools while solving problems is the focus of the video data gathered during two months of the second semester of the year. Given the dual nature of their role as participants, the choice of the individuals required a great deal of thought. I waited until the beginning of the second semester to make the final choice of these participants. I value opportunities to learn from students who struggle with mathematics and have negative experiences in mathematics classes; therefore, I did not want to choose only the strongest students as central participants. However, I wanted to choose students that I felt would engage with problems and use the technology tools to explore them. Therefore, I excluded those students who did little to no work during class as possible participants. Hindsight forced me to question this decision as I suspect these students would provide interesting data pertaining to the questions focusing this study.

The most valuable characteristic for a participant was their willingness and comfort to tell me what they were thinking and feeling. I based my selections primarily on my belief that the students I chose would share openly with me whether or not they felt like what they were saying or doing was something they thought I wanted to witness. I made this point explicit when I first informed the students that I was interested in having them participate in such a capacity. I gathered the four students in the hallway in the afternoon. The teachers conducting the classes each student was in agreed to let me take the student from their class for an undetermined amount of time. I explained to the group that I wanted them to work with me as participants of the study. I explained that their grade in class would not be affected by their decision and that I would not be mad if they chose to not be a participant. They all agreed, seemed excited, and proud to have been chosen. I shared the student assent form (Appendix 4) with each of them and explained its purpose and content. They had no questions about the form. I then gave each two copies of the parental consent form (Appendix 3) and told them their parents also needed to agree to have them be participants. I explained what the parental consent form stated and requested that they be returned the next day and signed by their parent(s) if they decided their child could participate.

I wanted the group of participants to be representative of the various subgroups of the population of the school and the class. Originally I decided to pick three central participants from this group of 7th graders. By choosing two girls and one boy I would represent the composition of the class with respect to gender. Choosing one black student would yield a small group representative of the ethnic composition of the school and this particular class. I decided to include a fourth student because I could not decide between two of the white girls. Additionally they had displayed a proclivity to work collaboratively with one another and I believed there was potential to collect rich data related to their efforts to work together as they used the technology tools.

Subjectivities as Teacher/Researcher

As do all researchers I carry subjectivities into my research efforts. Addressing these, it must be apparent that I place high value on one's mathematical learning. I strongly believe that those who develop the capacity to come to know mathematics at a level beyond what is currently common among many American students will prove to make these individuals more viable as life's problem solving activities present themselves. I believe that one truly learns mathematics when engaged in problem solving activities such as those that I intend to offer to students. Thus I place high value on such activities and feel that they are very worthwhile expenditures of one's time. Additionally I will encourage students to develop their own problems and will be easily distracted to encourage the class to pursue an original problem of their peers.

Perhaps of greater consideration of subjectivity, I am personally motivated to use technology to solve problems. On many an occasion I have found myself embroiled with effort related to using technology to solve a problem and having lost complete track of time as well as awareness of what is going on around me. In short, I believe that my personal feelings about using technology to solve problems must be kept in mind to remain certain that I do not interpret data in a way I hope it could be interpreted and rather in a fashion that is truly representative of what occurred.

As many in the Western culture have been observed to do, I also place myself, and my needs ahead of that of the larger group. I believe this leads me to remind myself to not lose sight of the individual while focusing on the constructs impacting their experiences with school mathematics. It is the person's identity that helps a researcher to understand more deeply what they are observing and possible reasons to support the inferences that are made.

Finally, worthy of note is the fact that I deeply value the importance of learning about a student's affective experience while solving problems. Having taught in public schools for more than five years, I invested a tremendous amount of energy and effort in promoting an emotionally comfortable and motivationally stimulating setting for children to learn mathematics. This effort may present yet another opportunity for me to allow my personal feelings to impact the work I will do. Also of concern is the fact I used an interpretative analysis of the qualitative data I collected, yet I necessarily was deeply involved with the setting. Therefore, it was important to keep in mind that I was attempting to understand what is transpiring with the students' affective experience and not allow myself to misconstrue their reactions in relation to my working with them. Finally, I recognize many students may have interpreted my role of teacher as meaning I have all the answers to the problems. Thus, I will have to be cognizant of asserting my own thinking rather than working to elicit the understandings my students are developing.

CHAPTER 4

Data Collection and Problem Focused-Timeline

As I alluded in the previous chapter, I gathered data from a variety of sources. I used electronic files to keep track of the plans I developed for the course. The field notes I used to keep track of my reflections are another form of data collected. Since my colleagues and I discussed problems my students were attempting during our weekly MLC meetings, the notes I wrote to summarize those meetings also function as a data source. Another important source of data are the student artifacts I collected throughout the year. These include written work students produced to express their thinking about different problems the class attempted. Routinely students wrote paragraphs in an effort to describe ‘what we know.’ These represent another type of student artifact. At the end of the year I collected students’ notes for the year. Few students had maintained complete sets of notes for the entire year. I attribute this fact to the lack of organization I required as the teacher and also to the students inability or lack of motivation to organize their notes for an entire year. I also conducted informal and semi-structured interviews with the four participants during the year. The recordings of the semi-structured interviews and the notes I developed to summarize the informal interviews form another source of data.

The above data operate at a secondary level for the investigation of the questions posed. The primary sources of data are the electronic files students produced during the year and the video recordings produced during the second semester. Having not pressed students to use a particular file-naming convention or how to be certain that all the files each student created were saved to an individual folder, the electronic files were sorted by computer station since my methodological choice allowed for this categorization. These files were further sorted by the date and time during which the file was produced. Confirmatory evidence of the identity of the author of each file was provided by the video recordings. Given the cameras recorded when students went to computers the videos are of different length and were created on different days of particular weeks. Table 1 depicts the days video recordings were created and the length of each movie.

Table 1: Video Recordings Date and Length

Jan 24 20’30	25 36’15	26 30’18	27	28
31	Feb 1 26’51	2 18’50	3 33’00	4
7	8	9	10	11
14	15	16 31’55	17	18
21	22	23	24 8’36	25 1:02’37
28	Mar 1 2’53	2 5’41	3	4 10’42
7	8	9	10	11
14	15 11’01	16 27’43	17	18 6’58
21 23’15	22 19’26	23 27’53	24 1’39	25

This table depicts the frequency and length of time students had opportunity to use technology tools during their activity. The gaps in the calendar where students were not engaged with computers represent the occasions when I was uncertain of their mathematical thinking related to the concepts we were investigating. Therefore, I chose to require students to demonstrate their thinking in writing and to engage in whole class and small group discussions until I felt enough conceptual groundwork was laid so students could attempt the problem I planned to pose.

Setting and Participants

In the rural city system where this study was conducted there are four schools, a primary, an elementary, a middle, and a high school. Less than one mile separates the campuses and the students who ride the district's buses travel with students from each of the schools. The student population is growing at a slow rate, slightly more than 3%/year, as more families move into the district. In October 2005, the 2004 fiscal year count showed 1528 students in the district. The district's school populations were all less than 400 (with exception of the high school that had 428 students) at the time of this count. The small size of the district is certainly one characteristic to attend to. Also, of importance are the statistics describing the number of students eligible for free and reduced price lunches. District-wide more than 47% of the students are eligible for free or reduced priced lunches and more than 80% of these students qualify for free meals. One third of the students in the district are described as members of an ethnic group historically labeled as a minority. Over 85% of these students are identified as Black, not of Hispanic origin.

The middle school and high school are contained within the same building. This proximity provides some advantages from a curricular stance, but also works negatively as it entices the middle school students to mimic the students in the high school they identify as ‘cool’. The middle school itself had fewer than 350 students during the year this study was conducted. The students are distributed nearly equally across the three grade levels. Approximately half of these students were eligible for free or reduced lunches. Of the students in the middle school 30% are identified as ethnic minorities and more than 90% of these students are described by the state as Black, not of Hispanic origin.

Our Classroom and the Available Technology Tools

In the middle school there were two carts, which acted as storage units, charging bays and wireless hubs, containing sixteen laptops each. The carts were housed primarily in the technology teacher’s classroom, but teachers were required to check them out in the media center, shared by the middle and high schools. These machines had wireless connection capability and ran the Windows operating system. With the wireless capability a user could connect to the Internet or their personal space on the school’s server. The server had space for each student. Many of the students had experience using these machines when they were enrolled in a nine-week exploratory class using these tools. Most of the students focused primarily on word processing skills in this class, but they learned about access to their personal space on the server.

These machines were beginning to show their age, three years, and evidence of frequent use. Several of them were missing keys and had questionable ports where external devices connected. As alluded to above, the technology teacher used these machines, but she only taught at the middle school in the afternoon. Thus the carts were free for use in the morning by the faculty at large. Most faculty members chose not to use the laptops because they would not be able to do the same activities with their afternoon classes since the machines would not be available. This fact was beneficial for my efforts since I only taught in the morning. Thus, I began the year by using one cart with my students on days that technology tools would support our efforts as a group. We, the members of the class, quickly came to the conclusion that the laptops did not operate dependably enough to make these tools worthy of our efforts.

Fortunately, there were other computers in my room for individual use when a student or group thought their problem solving efforts would be supported with these tools. These consisted of an antiquated Windows machine that had been replaced by a newer model the previous year. The older machine had been left in our classroom, and the new computer was set up and connected to the server for my uses, both administrative and pedagogical. I allowed students to use both these computers.

Additionally, I had acquired three eight-year-old computers powered by the Macintosh operating system. These were designated for surplus at a nearby university. As part of CPTM's grant with which the school district was partnered, the university allowed the machines to reside at the school. The machines could not connect to the school's server because it did not support Macintosh machines. These computers could access the Internet once the technology specialist for the district connected the four inoperable Ethernet ports to the network switch, thus making my classroom the only one in the building with all six of its Ethernet ports active. I also used two Apple laptops belonging to the university partner. These machines were nine and eleven years old at the time. Although the newer of these computers did not operate rapidly, it connected to the Internet and ran Excel and Geometer's Sketchpad sufficiently for purposes of this work. The older laptop would run Excel and was available to be taken from the closet and used if the software application was not available elsewhere. Having learned that the cart would not function effectively it was essential to acquire computers that could be used to provide students the opportunity to use the software I conjectured could support mathematical play. I acquired three more Macintosh computers from the university towards these ends. There were now a total of ten computers available to students to support their problem solving efforts. Six of these computers could access the Internet at any time, but only one could connect to the school's server, thus making the student's space on this hardware device inconsequential.

The classroom was organized to optimize space for the twenty three student desks, to allow computers efficient access to the five Ethernet ports along the south wall, and to locate the three computers where participants would work and be videotaped away from the students I did not have permission to videotape. These three criteria and the installed white board along the east wall led to this side being the front of the classroom. Along the south wall of the classroom the two Windows computers were situated side by side on a mobile cart. Only the newer machine was connected to the Ethernet. Next to the cart was a long, wooden-topped, wobbly, squeaky table. This table held three of the Macintosh computers, all of which were connected to the Ethernet. All monitors faced into the classroom so I as the teacher/researcher could monitor the students' activities and call attention to particular efforts I felt groups or the whole class should have the opportunity to view. Next to this table in the corner of the wall was a student desk holding the more functional of the two Apple laptops. The desk originally faced the wall so that the monitor was viewable from the center of the classroom; however, the students who commonly used the computer on the desk quickly decided to turn the desk to face the wobbly table. This allowed another student to slide a desk alongside so that two students could work together at this machine. It also afforded the student privacy to work without anyone, me included, hounding over their every move. Along the north wall the remaining three Macintoshes were placed on a plastic folding table. This area was recorded by the two cameras.

The Students

In the school where this study was conducted most of the children experience their entire public school career. Of course, there is the inevitable transfer and influx of students, but many of the students in my 7th grade class had attended the district's schools since Kindergarten. Those students who had not attended schools in the district, attended public schools within a thirty-mile radius save for two girls, who had previously attended a parochial school less than fifteen miles from the district.

The class was comprised of between 20 and 22 students throughout the year as new students entered the school and others left to attend other schools. Eighteen of the class members were enrolled in the school for the entire year. Of these students 12 are girls, 4 are black and 8 are white. Two of the boys are black and 4 are white. In talking with colleagues early in my work in the district, I described the students as largely representing 'good, down-home kids.' Although the students could act in ways contrary to established school norms, these instances of misbehavior were largely minor infractions. The students in this class were no different.

The mathematical abilities of these students varied. No student was one of the strongest in the grade level since none were in the tracked upper level class Henry taught. As further evidence these students were not the best mathematics students, on occasions when all 7th grade students took standardized tests required by the test or the district, five of the eighteen students went to separate testing rooms in order to meet the requirements of their individualized education plan (IEP). Of the thirteen students, who remained in our classroom for such testing situations, two had provisions in their IEP to allow for extra time for such tests. Thus, the students as a whole group aligned with my characterization of students I most value opportunities to work with as described in the methodology chapter.

Faith

The four participants are Faith, Kathy, Walt, and Wendy, all pseudonyms. Faith is a black female. She was a member of the basketball team and participated in a variety of other extracurricular activities including a holiday play produced by 7th grade students and their Language Arts and Reading teachers. Faith had attended schools in the district for her entire educational career. She lived with her mother, father, and 23-year-old brother in her mother's parent's house. Many of Faith's friends acted in ways that were contrary to acceptable school behavior. Faith was able to negotiate being friends with these students and also to continue to act in ways all her teachers deemed acceptable. Her current and former teachers described her as benevolent and a kind soul. All of my interactions with Faith support these characterizations. I was particularly interested to hear her words about how she negotiated the acceptable school norms and maintained friendships with students that did not align their actions with these norms. In our end of year interview I posed questions to Faith to try to understand this balancing act she performed. She told me her friends had told her she "acted white." She then shared her perspective with me that it did not imply ethnic identity to try to get positive outcomes from school. For her, school was a place where people could learn new things. She described the potential for learning as an "amazing thing" and truly valued opportunities to learn about new ideas. Therefore, I assert her goal trajectory took on a mastery orientation more regularly than a performance orientation.

From the first week of school she displayed a comfort and willingness to express her mathematical thinking. She accepted probing questions well and would persist in her efforts to explain her ideas. Faith offered incorrect reasoning to support her ideas on multiple occasions, but rarely gave up immediately when she learned of her mistakes. She attempted to help her peers who were confused and displayed patience with these students many times. She was considered smart and to be “good at math” by her peers. I attribute these characterizations to Faith’s ability to monitor and regulate her activity. On multiple occasions I observed Faith working to understand an aspect of the mathematics we were engaged with rather than giving up or requesting assistance from a more knowledgeable other.

For Faith the transition she experienced was more positive than negative. She reported enjoying the chance to try to determine solutions to problems rather than doing multiple exercises that made use of a procedure demonstrated during class. She also reported technology tools provided an enjoyable avenue to learn more mathematics. Faith stated her favorite aspect of the course was the instructor and the opportunity to work with her peers when trying to solve a problem.

Kathy

Kathy is a white female. She had not received all her education in the district. Her family moved to the area from Pennsylvania when she was in third grade. Kathy lived with her mother, maternal grandmother and step grandfather on a fifteen-acre property. She reported she did not find many of the extracurricular activities offered at the school to be interesting. She told me she enjoyed riding her mountain bike at her house and up to the cabin on her family’s property. She also enjoyed playing with and tending to the bevy of pets, a dog, cats, ducks and fish, at her house.

Kathy does not fit with the mainstream group of students at the school. She seemed comfortable with this fact perhaps because she appeared to be accepted for who she was by her peers. For Kathy her own personal identity was more important than being accepted by the larger group. One form of evidence of this statement is her expression of her musical interests. Unlike most of her peers who were more interested in popular music of the times, Kathy routinely spoke about her affinity for Slash and his early band Guns & Roses. She also could tell a person more about the rock group Kiss than many people my age. Other students were not familiar these groups. However, her peers rarely tried to put her down for having interests other than theirs; instead, the students would ask questions of Kathy to try to understand why she liked these individuals. Kathy would offer her reasons and seemed not to be affected if her rationale was accepted as valid or not.

Mathematically I describe Kathy as a questioner. Early in the year she demonstrated an ability to pose questions to her classmates and teacher. These questions often required higher order thinking and demonstrated Kathy's curiosity and her efforts to extend the topic being discussed. Kathy also exhibited a willingness to ask questions when she was confused about a specific procedure. These questions were not posed instantaneously. It often seemed Kathy had done thinking of her own related to the inquiry before posing her questions. She did not compute with the utmost proficiency but arrived at correct answers for computations more often than not. Overall Kathy was an average mathematics student, but unlike many average students I have worked with in the past she did not appear to be driven by grades. Rather Kathy was more interested in understanding the 'why' of mathematical topics.

From the first week of school I viewed Kathy as one the students I intended to choose as a participant given the qualities of curiosity she possessed. In fact, I believe it was this inclination that convinced me to include a fourth student as a participant. For her the transition between classes offered positive and negative consequences. She stated she was pleased to have the chance to think about problems for “more than five minutes and then move onto the next one.” However, she did not enjoy the inclusion of technology tools. She reported not being fond of technology. Additionally she did not understand what the software was doing on several occasions. This statement is evidenced by her search for a calculator so she could fill the cells in an Excel spreadsheet with the correct numbers. Not realizing Excel operated as a calculator hindered her understanding of the software and I suspect her acceptance of the software as an acceptable tool to support her learning.

Walt

Walt is a white male. He lived with his mother, stepfather and their four year old daughter. He was the centerfielder on the baseball team. He reported enjoying riding his four-wheeler at his grandmother’s house, who also lives in the district and with whom he spends time regularly. Walt is more interested in girls than many 7th grade boys. During the year he ‘went with’ an 8th grade girl and shows no reservation to flirt with the high school girls and danced with several at a combined dance. Although not all of his schooling experience has been in the district, he transferred midway through fifth grade, the other school he attended is in the same county and has many similar characteristics.

I remembered Walt on first sight on the first day of the year. He was a student in the class of Brian’s I visited most frequently during the previous year. Perhaps it was Walt’s medium length permed hair that allowed me to remember him, but some of his less than stellar mathematical remarks identified him as one that did not learn mathematics easily. I talked about Walt later with Brian and he confirmed Walt often struggled mathematically. Walt was likely to disengage when things became difficult. He reported not working very hard in class because it was often difficult for him. He understood I wanted students who were struggling to ask questions and stated, “a lot of times I just didn’t know what to ask.” When I questioned him further in our end of year interview about the likelihood he would give up rather than persist with a difficult task, he responded he really had to want something if he was going to work hard at it. He offered earning a starting position on the baseball team as a goal he would be willing to work for, but since he was getting acceptable grades in class he didn’t feel compelled to struggle for long periods of time.

For Walt the transition to our class was largely positive. As stated earlier he did not feel strongly compelled to persist when he confronted a difficult problem. Instead of being concerned with the grade he was going to receive, Walt took multiple opportunities to further his social goals of being liked by his peers and being considered a cool guy. He was routinely observed to be off task mathematically. Thus the transition actually facilitated his performance avoidance goal orientation because he could disengage with a given task and not suffer performance-related consequences. In our end of year interview Walt told me he preferred our class this year to his past experiences with school mathematics. His statement that “This year we got to think about a problem for a longer time instead of having a short time to think and then move on to another problem” offered one reason why he liked the course more than others. He went on to state he often felt behind in other mathematics classes and having the chance to think about a problem for a longer period of time was helpful. Walt went on to tell me he enjoyed the chance to use computers in class. He did not use computers in other classes and was pleased to have the chance to “play” with the computers. He explained to me playing with the computer helped him to learn how to use it much like “messing around with the controller” of his PlayStation helped him learn how to use the gaming system. Overall the lack of formal assessment and rigid structure allowed

Walt to feel comfortable in his experience, but likely did not further his mathematical learning to a great extent.

Wendy

Wendy is a white female and was close friends with Kathy, who she often worked with in class. She lived with her mother, father, and older sister. She had always gone to school in the district. Wendy was a cheerleader and provided a strong base for the few aerial maneuvers the squad attempted. She is outgoing and can be rather silly, but is not as shallow as cheerleaders are often considered. She was at the position in her life where she "hated" most anything a person mentioned. Additionally she was not shy about these feelings in one on one conversations or in front of a group of her peers.

Wendy is a proficient mathematics student. She thought deeply and learned new ideas quickly. She was accustomed to receiving good grades in all her classes even though she reported, "I have always hated math." Wendy did not support the learning of her peers effectively. She was commonly impatient with her classmates and tended to tell others what to do instead of listening and responding to questions another student had asked her. She and Kathy worked together at one of the participant's computers, but Wendy was largely in control of the mouse and the directions of study. In an interview conducted with both Wendy and Kathy, Kathy pointed out the likelihood of Wendy becoming frustrated with others inability to think mathematically at the same rate or along the same line as she did.

I decided Wendy was a good choice for a research participant when I considered how the transition from one course to the next was impacting her. Wendy was very successful in her previous mathematics classes and expected a teacher to tell her when she was right or wrong. When I did not act in such a way she experienced perturbation. For example, during one class meeting, she struggled to provide reasoning for her mathematical assertion. I refused to let the assertion be offered without support. Her efforts to disengage were not accepted and my pushing her to explain her thinking drove her to tears. When we later discussed this incident she related never having been in such a situation in a mathematics class and did not know what to do. She did forgive me for pushing her and explained she later understood what I had been trying to do. She described her goals for school mathematics in terms identifying her as having performance approach goals. She did enjoy not having formal assessments because “you don’t look dumb” in front of your classmates then.

Problem-Focused Timeline

We began the year doing those first day of school activities that I think are important as well as some that other educators in the school thought were important. These included distributing student agendas, which were purchased by the district, discussing the school rules printed in the agenda and pointing out which included forms needed to be signed and returned. As a class we decided on a day by which these were to be returned and an appropriated consequence if they were not. Without making a big deal of it we had made our first decision as a group and determined consequences if a member of the class did not adhere to the decision.

The Locker Problem

One of these first day duties I was happy to carry out was the assigning of lockers to the students. I have always felt that lockers allowed a student a space in the school that was theirs and were important for students to have. Given the disparity of the physical sizes of the students in my class there was practical reason to consider whether a student would get a top, middle or bottom locker. While we were determining who would get which locker it became important to know which numbers coincided with top, middle, and bottom lockers. I told the students I had the lockers numbered 127 to 150 to assign and asked how many lockers that allowed us. Eventually most students realized why there were 24 lockers available to the class.

Before we went through the process of determining which kids wanted which ‘level’ of locker, I stepped into the hall and looked at the lockers right outside my door. I returned and told the students that 94 and 97 were both top lockers. I then asked how we could use that information to determine if the locker a student received would be at the level they desired. This problem fostered thinking from most of the class. Many of the students had a preference for the level of their locker, so they had a motive to engage in determining a solution to this problem. We had begun the first problem of the year.

Students approached this problem in a variety of ways. Some wrote columns of three numbers while others chose to write horizontal lists of numbers. Many students offered ideas about which numbers corresponded to the different locker levels. However, when pressed to supply the reasoning they used to determine these solutions, students had little success describing what they thought about in order to arrive at their assertions. It is at this point that students began to express confusion about how to operate in this environment.

We considered extensions of this problem over the next several days. These included determining the location of lockers numbered 214 and 1007. We thought about the situation if there were four lockers in a column. Our mathematical conversations lead to the discussion of multiples and factors. Students offered their understanding of multiples and I generated a list of the multiples of three from 3 to 57 with Excel and projected the spreadsheet on the front board. I knew that Brian had included divisibility rules in the topics that he incorporated into the curriculum of his classes. I wanted to see if any student remembered the divisibility rule for three so I posed a homework assignment to explore patterns in the first 20 multiples of 3. The next day we discussed students' ideas. Not surprisingly, no one offered the connection the sum of the digits of each number gave another number in the list.

The Sum of the Three Largest Primes Less Than 100

In an effort to connect to broad number theoretic concepts involved in the locker problem, I posed the problem of determining the sum of the 3 largest primes less than 100. During the exploration of this problem we developed definitions of multiple, factor, and prime. We used Excel to create a prime sieve and to look for general patterns in the hundreds board used for the sieve. This occasion represented the first opportunity the students had to use Excel in their problem-solving efforts. I had quickly demonstrated the construction of the hundreds board and how one may use Excel to highlight particular cells and then let the students try on the computers in the classroom.

The context of this problem, which we explored for more than a week, also allowed us to develop important mathematical ideas related to the communication of ideas. As students offered conjectures I worked to help the class members understand the relevance of such assertions for mathematical activity. We went on to attempt to refute conjectures with counterexamples and I explained how such examples played a role in mathematics. As evidence these occasions of me 'talking at' students were understood, students began to use these words in their discussions of mathematical thinking. Also, in the context of this problem and the search for patterns in the hundreds board I explained the difference in general and specific examples. These were not concepts that everyone understood quickly. However, as the year progressed students started using these terms in their talk with me and in large group settings.

While searching for patterns in the hundreds board, we opened our class discussion to incorporate ideas of expression, order of operations, inverse relations and undoing operations.

These big ideas were largely driven by Kathy's questions. As our discussions meandered through the topics listed, I realized some of the perturbations students were experiencing. One way they communicated their lack of comfort with my efforts to focus the discussion beyond what they already knew was evidenced in their questioning about why they were in this particular class. Apparently their peers had told them they were in the slow class since they did not have Henry for a teacher and all the other 7th graders did. I suspect since they were struggling to understand the topics we were discussing, they had added reason to wonder if, in fact, they were in the slow class. Also, several students expressed concern about the fact that they had not received their books. I took this concern as further evidence they were unsure what sense to make of the transition they were experiencing.

Olympics Project

During the last week of August the students in all my classes began an investigation of an Olympic event they wanted to learn more about. Since the Olympics were taking place, I decided this would be a good opportunity to connect mathematical ideas to something they could all find interesting. Of course, not everyone was as interested in the Olympics as I was (and still am. I think the Olympics are great.) I posed the task to learn more about an event in an extremely open-ended fashion. Students not only had to pick an event, but groups of two to three students were also responsible for gathering data related to the event. They gathered data from primarily online sources and it became apparent after two days few had the ability to extract 'useful' data from the content they viewed on the Internet.

Since the students had made little headway with the task as I had defined it, I offered some assistance. Having decided I did not want to tell them exactly what each group should do, I gave each group a set of data I had compiled from the official Olympics web site. Each of these sets of data I distributed were organized in such a way to create a new problematic situation for students, namely how to make sense of the tab delineated text appearing as a table on the Internet. Some students made direct comparisons between the two forms of data while others simply tried to interpret the material I had provided them.

I also offered a variety of mathematical topics they could choose to think about relative to the data. These included ratio and scale drawing, area and volume, and mean among others. The students' progress was slow and rarely focused on one topic for an extended period of time. This evidence provided support for my beliefs suggesting students would experience a variety of transitions when attending this course. One of these transitions, working independently, seemed not to be as difficult for students to cope with as the fact their classmates were doing things in class which were different from other class members. I believe the fact all students were not doing the same thing in class provoked perturbation in students' experience.

Having exhausted multiple ideas and the patience of many students with the Olympics project, we continued our efforts until the fall intersession break, a two week break provided for by the district's modified year-round calendar, by exploring topics as a whole class which arose while students worked on their Olympics projects. Building from the concept of ratio and scale drawing, we worked for a further understanding of the concept of proportion since students who produced scale drawings intelligently chose scales requiring no computation in order to produce their representations. In this endeavor I tried to support student understanding of the mathematical justification for why cross multiplication works when we attempt to solve proportions. This effort led to our thinking about operations with fractions. Here, I integrated the commutative, transitive, and distributive properties. Finally, just before the break I administered a written assessment. I intended to use it as a tool for the students' learning so I returned it the next day with only comments for further thinking written on it. Students were to explore these comments over the break.

Two Joggers, A Builder, Some Geese, and Paint Bottles

After returning from the fall intersession break, I posed four problems to all my classes. The 7th graders explored each of these in an order as chosen by individuals. I picked these problems because I wanted to foster the notion of different students working on different problems and then reporting their progress to classmates who had yet to explore the particular problem. Additionally I felt each problem built on topics we had discussed previously. The four problems are stated below.

The Jogger Problem – Two joggers are running around an oval track in opposite directions. One jogger runs around the track in 56 seconds. The joggers meet every 24 seconds. How many seconds does it take the second jogger to run around the track?

The Builder Problem – Builders use a ratio to specify the pitch of a roof. For example a “four : twelve roof” means a roof that rises four units for every 12 units of span – goes up 4 units vertically for every 12 units across horizontally. Suppose a builder whose knowledge of this building convention is faulty, believes that four : twelve means a roof that spans four units for every rise of 12 units. Assume the front of the house is 40 feet across and 20 feet high. How high is it from the ground to the peak of this roof.

Paint Problem – To make a shade of orange paint that you like, you must mix 2/3 of a bottle of red paint with each 4/5 of a bottle of yellow paint that you use. You need 88 bottles of this orange paint. How many bottles of red paint will you need and how many bottles of yellow paint will you need? (All bottles are the same size.)

Geese Problem – A flock of geese on a pond were being observed continuously. At 1:00 P.M., 1/5 of the geese flew away. At 2:00 P.M., 1/8 of the geese that remained flew away. At 3:00 P.M., 3 times as many geese as had flown away at 1:00 P.M. flew away, leaving 28 geese on the pond. At no other time did any geese arrive or fly away. How many geese were in the original flock?

By mid-November these problems were still around. At this time we worked largely as a whole class rather than having different groups working to solve different problems. The decision was fueled by the lack of substantive progress on any one problem. I thought I had done a respectable job in supporting students as they worked, but few students made any substantial progress. As a whole class we tried to work with the jogger problem. Over the days we worked with the jogger problem students definitely had an opportunity to deepen their understanding of rational numbers and factors. By drawing pictures, using student's counterexamples to refute the assertions of others, and using as much patience as I could muster we eventually determined a solution of the problem. More importantly, to me at least, we as a class had participated in mathematical activity. I did not tell students when they were right or wrong, but rather encouraged others to examine the validity of their classmates' conjectures. It was particularly satisfying to view students presenting counterexamples to prove their peers incorrect without being rude in the process.

The class decided to next consider the paint problem. As I realized during their small group efforts, the rational numbers used in the ratios were the most problematic aspect of the problem. Over the next several days we continued to develop understanding of rational numbers.

Finally, we worked to solve the builder problem, we did not explore the geese problem as a class. In small groups students evinced an inability to produce a visual representation of the problem. Not creating a visual representation proved to hinder their progress. Once we as a class produced a visual representation of the problem, students needed to understand the roof would typically peak at a point on the perpendicular bisector of the segment used to represent the base of the house. Understanding how the defined ratio influenced where the peak of the roof would be in the visual representation proved difficult for many of the students. As a class we talked about the connection and then many students determined the height requested. Because I had planned to incorporate slope into future posed problems for this class, I then posed multiple extensions of the problem. Again, I wanted students to work with different situations and then to explain their work to the large group. On this occasion the students efforts were productive. Several individuals offered their thinking to the whole group and responded to the questions posed by their classmates. The class was struggling with the transition, but most were persisting in their efforts to engage with the problems posed.

November 10, 2004 – The Annoyance Graph.

With the intent of allowing the students to express their stress and frustration since we had been working on these problems for a good deal longer than they had previously worked on any problem, I helped them think about making annoyance graphs. They were getting on my nerves, I was irritating them, and several students were irritating each other. We represented levels of annoyance as time passed on the first quadrant of a coordinate plane. The students wrote paragraphs describing what the graphs they made meant to them.

I truly wish I had made better use of this idea throughout the year in a variety of circumstances. Not only did the production and explanation of these graphs seem to provide a needed release for many members of the class, but the production of the graphs was also an avenue to think about representing different situations graphically. Of course, not all the productions of such graphs would have to be annoyance graphs.

With the intention of concluding the semester by laying groundwork for the problems I would pose while the students' actions were being recorded, we extending our work with visual representations and dimensions to include other aspects of geometry. I used scale drawing as a context to motivate thinking about area. I demonstrated measuring the top of the table at the front of the class (it is a trapezoid) and asked the students to do a scale drawing. We discussed how to determine area and used the mixed number measurements to compute areas of the original and the image. Students were then free to measure other objects to determine the values to use to find area. This activity very naturally prompted a discussion of the differences in two and three-dimensional objects and measuring their varied attributes. We did not explore volume beyond the conceptual level. My intentions were rather to continue the process I demonstrated of producing a scale drawing of an image, finding the area of the original and the image, and finally comparing the relationships between the two for a variety of student-generated cases. This goal was not realized to the extent I had hoped.

The Fence Problem

After returning from the winter break, I followed up with some of the ideas we had discussed in December. This work led to posing the fence problem, one of the two problems on which analysis was focused, on Wednesday of our second week back at school. This problem, found on Jim Wilson's server, informs the student 100 yards of fencing are available to enclose a garden. The problem then goes on to pose multiple questions regarding the area of shapes one could construct with equivalent perimeter. A suggested getting started point was students could describe the dimensions of the proposed shapes, find their area and create charts with which to organize this data. We began trying to understand the problem in this fashion. Next, students explored several of the directions described in the statement of the problem. I attempted to support students' understanding of the big idea, the change in area of the polygons as perimeter remained constant. I felt compelled to make such an explicit statement because many students appeared content with their efforts after finding the area of one figure. Even though many were using GSP to create a shape and find its area they were not driven to produce many or to keep track of the values they measured with GSP. In order to focus the students' work I decided we would all approach the problem from a direction suggested in the problem statement. We worked only with rectangular regions that could be formed with the given perimeter. Students were encouraged to use formulas, manipulatives, and to make charts. Excel and GSP were available to them during these efforts. Students used Excel to build a table of different rectangle dimensions and the associated areas. I asked students to write about observations they saw in the table. We will also used Excel to explore graphs where a dimension of the rectangle was the independent variable and the area of the rectangle was the dependent variable. This representation provided a connection to functions middle school students do not typically experience. We did not spend a great deal of time with this connection, but students were privy to mathematics of this problem beyond the obvious geometric topics.

The statement of the problem also offered other directions for investigation. One direction all students used GSP to explore was the area of regular polygons with a perimeter of one hundred. To facilitate the students' efforts to think about this aspect of the problem we used the transform menu in GSP. Beginning with a point constructed on a circle, I explained one way students could construct regular polygons. By demonstrating the repeated rotation of a point on the circle about the center of the circle, students saw a construction of a regular polygon, in particular a regular decagon. Previously I had demonstrated rotation and reflection with the transform menu in GSP and I had allowed time for students to use these options in their own sketches. One reason to explore regular polygons was to further the students experiences with these transformations. My larger motive was for students to use GSP to explore regular polygons with perimeter of one hundred. Using the software to construct the polygons allowed the students to find area without attention required to sketch accurate polygons, create interior polygons to which an area formula may be applied, precisely measure the appropriate dimensions, and correctly calculate the area of the polygons.

I intended to direct students to measure the perimeter and area of each regular polygon they constructed. However, the necessity to create a perimeter of one hundred forced the students to drag the polygon so that it became larger than the viewing area. I had hoped students would find this task inefficient and be open to the idea of scaling the polygon so that it was easier to view. The scaled down version of the polygon would have allowed for a return to the scale drawing and its related area work I had hoped to engage students in before the winter break. Again this direction was not followed.

Fortunately, however, I was able to let the students dictate the direction our work would take. They had used GSP to construct regular polygons with 24, 36, 72, 120, and 180 sides in addition to every factor of 360 less than 24. The students' efforts with the software continued and I realized that the areas were going to converge to the area of the circle and the students may be able to make sense of this because as the number of sides in the polygon increased the figure was approximating the circle used to construct it. As a class we built a table with this information largely derived from Wendy and Kathy's efforts as well as another handful of student's efforts. We produced a graph to represent the areas of regular polygons with increasing numbers of sides. The students thus experienced another typically not middle grades aspect of mathematics, convergence of a sequence, emerging from the context of a problem they had solved.

I hoped the students would choose another of the suggested directions or one of their own to continue extending this problem. Many students were using the technology tools effectively. However, I became distracted by the activity of students using GSP on the computer connected to the projector. Since the projector was on, I and the other students could see that one of their classmates had discovered how to make a point animate randomly in the plane. I took this opportunity to show students how they could use GSP to animate an object based on its constructed relationships and also how to turn on a trace of an object. Within no time students viewed GSP create a ring inside the circle. I abandoned previous plans to extend the fence problem and focused the students attention on the mathematics of the ring created by tracing a side of the inscribed polygon while one of its vertices rotated along the circle. We spent the next days investigating mathematical relationships of this situation, which will be expounded in an upcoming issue of *Mathematics Teacher*.

Guess My Rule

Building on the students' experience with t-charts and graphed representations from the fence problem I next moved the class to determining expressions from a t-chart or producing a t-chart for a given expression. This choice was motivated by my desire to pose guess my rule, the second problem analyzed in order to address the study questions. Derived from a talk by Marilyn Burns at an annual meeting of NCTM, the class worked with the problem and the foundational aspects I deemed important for the majority of February and March. Burns had displayed student work that showed ordered pairs arranged in a t-chart. The students were to determine the operations applied to the numbers in the left column to arrive at the numbers in the right column. She stated students would generate a t-chart and then ask their classmates to guess the rule they had used in order to produce the pattern displayed. I intended to confine this problem to Excel. In short, students would be expected to produce a t-chart with Excel and a graph a classmate could view. The other student would then guess the rule used to create the chart and graph.

This problem was not fully posed immediately. Instead I wanted students to display an understanding of essential concepts that could facilitate success guessing a rule. We began by exploring different patterns. These were scenarios derived from some of the linear and non-linear relationships described by Cramer (2001). Different groups generated t-charts representative of relationships they determined in the patterns. I asked groups to write their t-charts on the white board and as a class we determined rules that could be used to extend the patterns. At this time I explained how to create graphs of these relationships with Excel as well as on graph paper. Students attempted graphing, but struggled to use the grid lines on the graph paper as useful aspects of the representation.

I chose this problem to provide an opportunity to explore numerical patterns and ways to extend some of these patterns. Also, by incorporating the graphed representations of the relations created I hoped to help students begin to see the connections between a rule that could generate a pattern and an associated graphed representation. Using technology tools to explore these topics allowed students to expend a greater portion of their cognitive capacity thinking about the relationships seen in the numeric and graphed patterns rather than having to attend to calculations and accurately depicted the graph. I did not negate the importance of computation and precision in producing a graph as seen in the number of days during this period of time in which students did not use software (see Table 1).

During the time when students were not using computers to guess a rule, the class grappled with the concept of slope, independence and dependence, inverses, and understanding a connection between the t-charts and the graphed representations. A guiding reason to not work on the computers was students were not able to demonstrate a working conceptual understanding of linear function relationships to my satisfaction. I chose to continue to facilitate class discussions about various aspects of the mathematics at hand. My tendency to not move forward until students could explain why the numbers they offered for positions in t-charts were correct drastically slowed the process of completing t-charts requiring student to operate with fractions. By requiring students have the beginnings of an understanding of aspects of representations of linear relationships I hoped they would have greater success engaging with guess my rule.

Pelicans and Fishies

With intentions of extending guess my rule I produced a t-chart with several rules and the associated piecewise graphed representation (Figures 1 and 1.1). I described a scenario about driving to a parking lot and then going for a hike as representative of the graphed representation. I requested that students move to computers and try to create a t-chart with Excel that would generate a graphed representation with a bend in it and then make up a scenario to relate to the graph. Students attempted this task and were largely unsuccessful. One reason I determined was the seemingly contrived nature of the scenario representing the graph. I next tried another approach by beginning with the scenario and producing a t-chart used to represent the scenario. Towards these ends I posed the original problem Pelicans and Fishies.

-1	8
-0.75	6
-0.5	4
-0.25	2
0	0

0.25	0.125
0.5	0.25
0.75	0.375
1	0.5
1.25	0.625
1.5	0.75
1.75	0.75
2	0.75
2.25	0.625
2.5	0.5
2.75	0.375
3	0.25

Figure 1

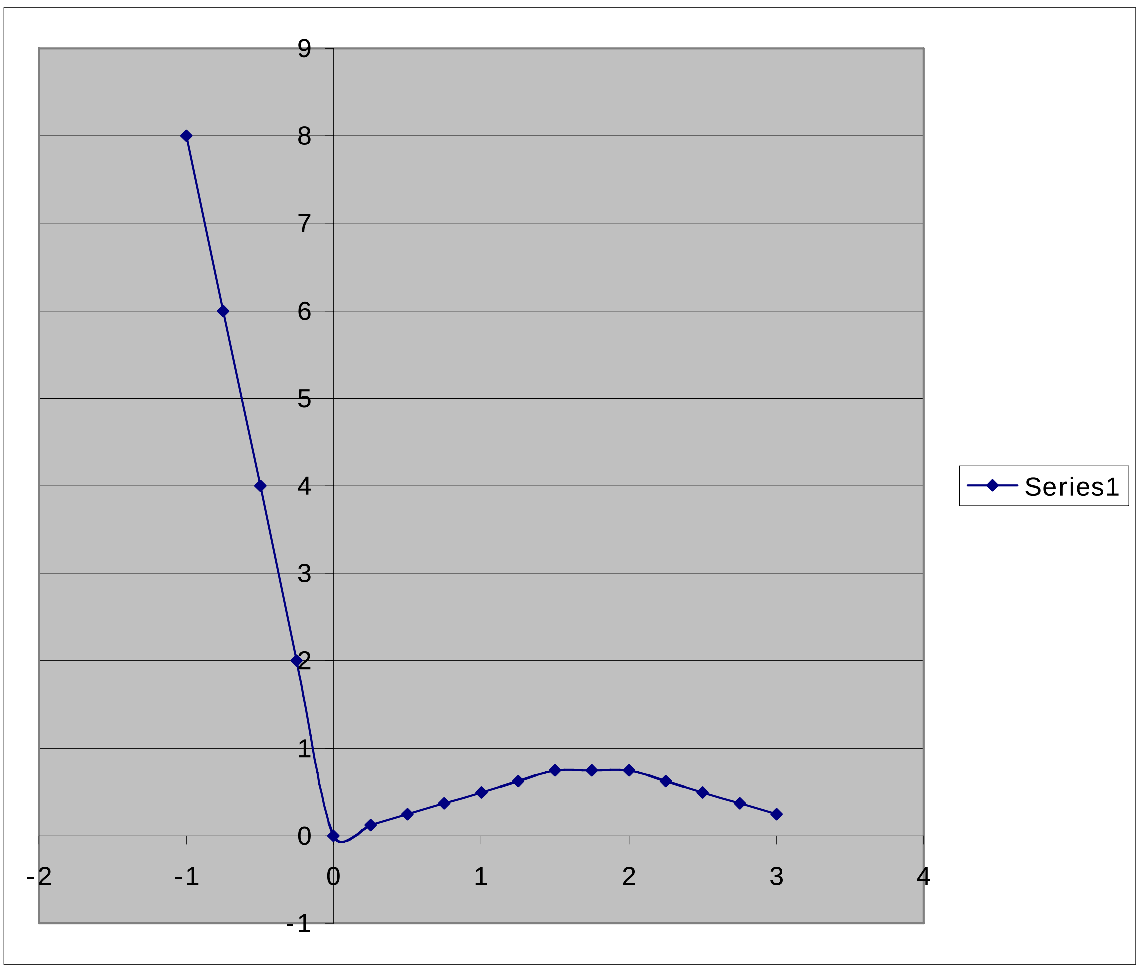

Figure 1.1

Students were shown a t-chart and graph (figures 1.2 and 1.3) and a description of the problem. In particular, two pelicans are eating fish at the rate shown in the t-chart. At a given point in time some other pelicans sense the dining pleasure of their compadres so four of them join the two dining pelicans. The six birds eat fish at the constant rate depicted. How many fish does one pelican eat in 45 sec? How long will it take the 6 pelicans to finish the fishies? The students worked with the representations to find support for their assertions. The computation with rational numbers again proved problematic for many students. We spent the class meetings remaining before the spring intersession break extending this problem and computing with rational numbers in other contexts.

0	100
0.75	97.75
1.5	95.5
2.25	93.25
3	91
3.75	88.75
4.5	86.5
5.25	84.25
6	77.5
6.75	70.75
7.5	64
8.25	57.25
9	50.5
9.75	43.75

Figure 1.2

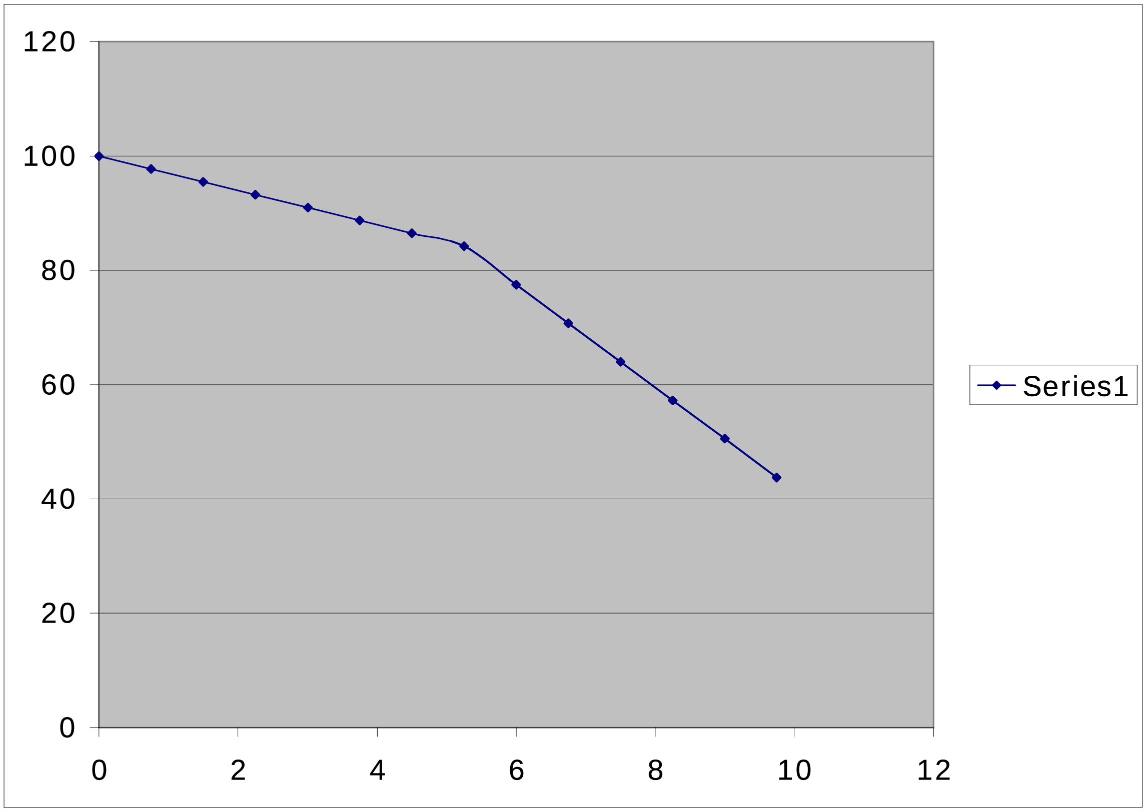

Figure 1.3

Final Projects

The spring intersession break concluded and students returned to school on April 11. The mandatory state testing was scheduled for the end of April. Thus over the next two weeks the students and I discussed sets of exercises similar to those likely to appear on the state assessment. The topics we discussed on a conceptual level all stemmed from students not understanding one of the exercises I supplied for their test preparation.

After the week of state testing concluded, I facilitated the students' efforts on their final project (see appendix 8). I attempted to allow the students to negotiate the standards for the project with me. They offered creditable points to attend to for the oral presentation. The written requirements were largely based on my suggestions, which they simply agreed with.

In general, students were to choose a topic that they found interesting and wanted to learn more about and describe the mathematics related to the topic. I decided to conclude our class with this final project for a variety of reasons. First, I wanted to see if the students would be able to search for and explore any mathematics that might be found related to their topic of interest. Having explored events of the Olympics earlier in the year and learning that the students had little ability to find data related to the event much less to apply mathematical thinking to the data that they did find, I was curious to see if several months had fostered any change in their ability to find data and explore the mathematical ideas related to these data. Second, the school as a whole was pressed with what to do with the students for the last four weeks of school. Since students recognized the high stakes nature of the end-of-grade tests, in large part they tended to view the serious work of the year to be over once the testing was completed. I had provided opportunities for the students to experience substantive mathematics I chose and wanted the end of the year to be solely focused by their efforts. Plus, I think we were all tired and needed a way to enjoy the end of the year with one another.

The students mostly worked in groups and explored topics such as music, fireworks, shopping, paintball, NASCAR, and home design. During each group oral presentation I required the audience members to write one or two things that the group did well and one or two things that the group could have done to improve their efforts. This data showed several of the students were able to think critically about mathematics the presenters offered or did not describe.

In general students chose a big idea they found interesting and then wanted to find out what their classmates and other students in the school thought about aspects of their general topic. For example, the group that chose to learn more about music conducted surveys in various classrooms (all the teachers were very welcoming to our multiple requests to interrupt and talk to their class, perhaps it had something to do with the ‘permission to interrupt letters’ I had students write, deliver to teachers, and then wait for a response to before surveying their classes) to find out which students preferred particular genres of music and which radio stations they liked. The group of girls who wanted to learn more about shopping, surveyed students about which stores they liked the best. They found that their choices of stores to ask people about did not resound with the school as a whole and therefore they included new stores in their survey in order to get a better sense of the stores that their schoolmates described as their favorites. Thus they saw firsthand how it can be important to alter a plan in order to gather more representative data for a particular question. Since nearly all groups allowed students to vote more than once when discussing favorites, we were able to discuss the mathematics of sample size and what might occur when certain people voted multiple times and others voted only once or twice. Namely we talked about how a group of several people could affect the results.

The Internet, used both in class and at home, was a source of data for the students. The boys trying to learn more about basketball and football found the dimensions of the playing surface and were then able to use these numbers to explore mathematical aspects of their topic. The media center provided a source of data for students as well. Students checked out books about their topic of choice and searched them for mathematical details. Often students struggled to find significant mathematics when engaged with the project. I attempted to provide direction without telling a student exactly what they might do. I was pleased with some aspects of these projects, namely the students’ flexibility and ability to critique their classmates work, but the projects did provide an instance when students had the opportunity to not engage in the mathematical activity without significant negative consequences.

CHAPTER 5

Analysis of Participants' Engagement, Technology Use, Play and Affective Experience

In an effort to analyze data relevant to the research questions I imposed a structure on the cases of each of the four participants. For both the fence problem and guess my rule, I first describe the student's engagement. The student's activity may be with the problem posed, one of their choice, or with non-mathematical activity. The description of the student's engagement with problem solving is focused generally on their overall engagement with the problem. Further analysis was focused on files the students saved during these period of activity. Second I describe the student's technology tool use. Third I describe playful aspects of the student's mathematical activity. Using student work and evidence of student's play to interpret the data, I address the first question posed. Lastly, given the student's engagement with problem solving while using technology, I describe the student's affective experience.

Wendy

Wendy's engagement with the fence problem

Wendy engaged with different aspects of the fence problem. She worked to develop tables representing the area of a rectangle given particular dimensions. She produced these tables on paper and with Excel. Figure 2 is a representation of a table Wendy and Kathy produced jointly. In addition to creating the table in figure 2, Wendy graphed the values to further engage with aspects of the mathematics of the fence problem. Images in figures 2.1 and 2.2 represent her graphs. When she typed,

> THE GRAPH RELATES TO THE NUMBERS BY THAT THE
> NUMBERS ON GOING UP REPRESENT THE AREA AND THE
> NUMBERS GOING ARCOSS THE BOTTOM REPRESENTS
> THE DIMENSIONS,

she demonstrated her engagement with the problem in a fashion I had suggested. This choice to produce work based on what I suggested was indicative of Wendy's performance goal orientation. I had not suggested specific numbers to choose for dimensions or how many entries a student should make in the table they developed. However, the choice to pose the problem without more direction potentially limited the experience of students with performance goals. Here Wendy exemplified this concern by not choosing to continue her table far enough to observe the area reach a maximum and then begin to decrease again.

Dimension of a Rectangle		AREA!!
5	45	225
6	44	264
7	43	301
8	42	336
9	41	369
10	40	400
11	39	429
12	38	456
13	37	481

Figure 2

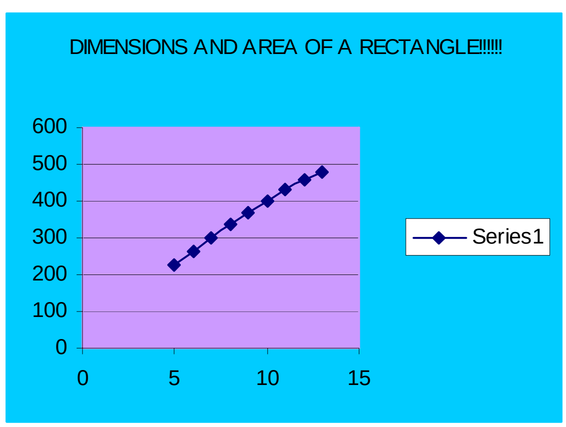

Figure 2.1

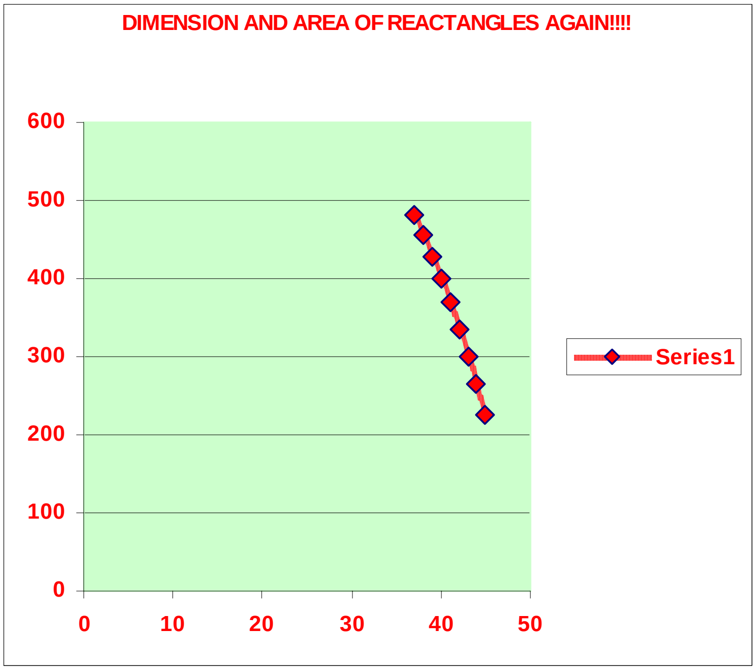

Figure 2.2

Wendy also engaged with the regular polygon aspects of the fence problem. After I demonstrated a method to construct regular polygons and then how to pull a vertex to approximate a perimeter, Wendy used this method to create various regular polygons with approximately equal perimeters. She provided one form of evidence of her efforts by producing a table with Excel (Figure 3). She also recorded the measured side lengths, perimeter, and area on paper. Two examples of Wendy's work are seen in figures 3.1 and 3.2, both of which were resized in order to fit the page. The "9agon" in figure 3.1 was created by rotating a point on a circle forty degrees about the center of the circle. Similarly figure 3.2 is an image of one of Wendy's files in which she constructed a regular polygon. She titled the file "22agon" although she rotated a point on a circle 15 degrees about the center of the circle, creating a 24-sided regular polygon. She only represented 22 of the sides' lengths which impacted her choice to label the file "22agon."

polygon	dimension	area
circle	r=15.95yd	799.32yd^2
pentagon	each side 20.01032yd	688.90138yd^2
9agon	each side 11.11155yd	763.24891yd^2

REGULARS		
TRIANGLE	33.3333333	446.17
SQUARE	25	625
PENTAGON	20	688
HEXAGON	16.67	721
7-GON	14.2857143	
OCTAGON	12.5	755
9-GON	11.1111111	763
DECAGON	10	770
12-GON	8.33333333	
18-GON	5.55555556	788
24-GON	4.16666667	792
72-GON	1.38888889	803
120-GON	0.83333333	
180-GON	0.55555556	

Figure 3

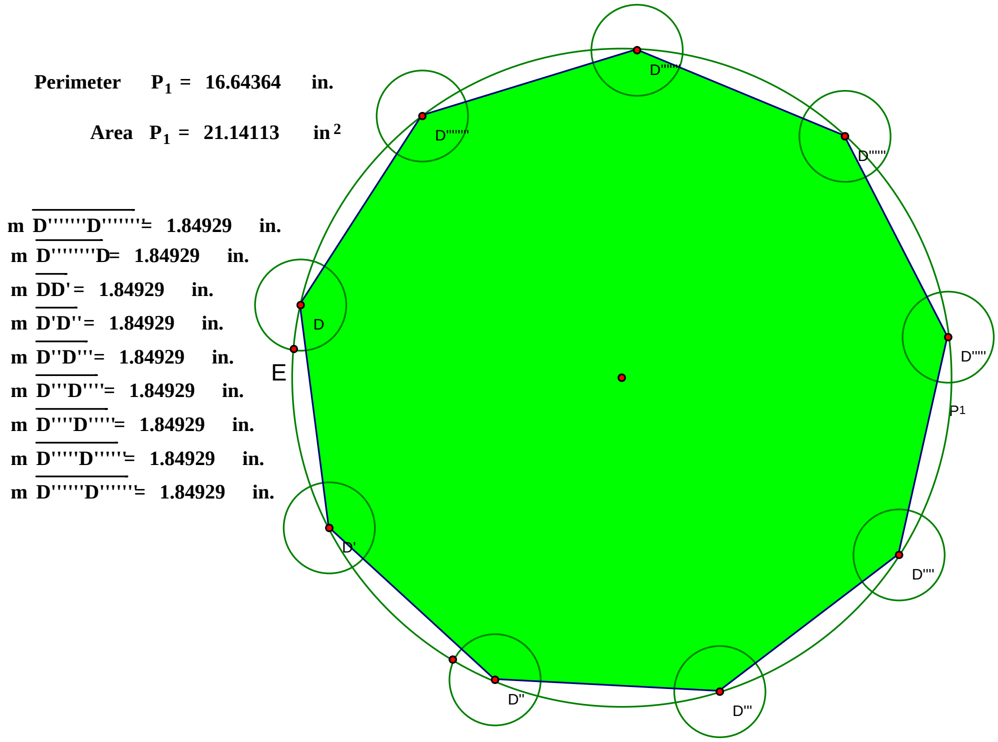

Figure 3.1

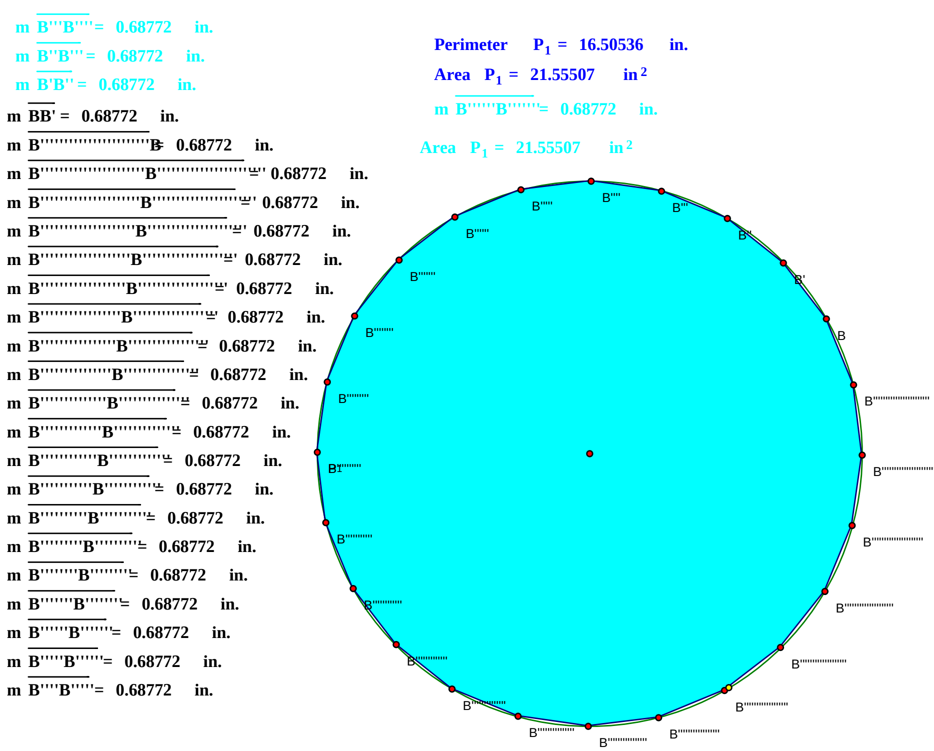

Figure 3.2

Use of technology tools

Wendy exemplified a prowess with technology tools in her efforts to engage with the fence problem in a fashion she interpreted as ‘what she was supposed to do’. She watched my whole class demonstrations and was able to mimic many of my actions with GSP and Excel. The videos show Wendy using the software consistently and with little need for support from others.

She used Excel to calculate values in figures 2 and 3. Particularly, in figure 2 she used an expression I had worked to support the class to develop as a whole. This whole group discussion took place while students were at their desks. Wendy moved to the computers and used the expression to generate the dimensions in the column labeled, “dimension of a rectangle.” She next used the software to calculate the area associated with each rectangle. In each case she filled down the column to iterate the formula for the other associated values, an important action from an efficiency perspective as well as a conceptual one. Wendy’s activity with Excel later in the year regularly made use of its ‘fill down’ capability.

Her work with Excel to generate the image seen in figure 3, was largely of a record keeping nature save for her formula use to determine the lengths of the sides of each regular polygon. She did not use the tool’s ability to calculate these side lengths in every case. For example, she manually entered the values for lengths of sides of the regular triangle, pentagon, hexagon and ‘9-gon.’ After typing a formula for the length of the side of square and observing the result, Wendy’s mathematics knowledge would easily allow her to enter the side length of the regular pentagon. These actions with Excel exemplified her prowess with the tool as well as her ability to decide when to use certain aspects of the software and when it was reasonable to use her mathematics knowledge. Her choices to use existing mathematical knowledge or the capability of the software reflected Wendy was not operating without thinking about the mathematics as some fear technology tools may promote students to operate.

Wendy's work with GSP was also effective and efficient. She quickly learned how to use the software to support her efforts to engage with the regular polygon aspect of the fence problem. As stated above, she mimicked a procedure to construct regular polygons I had demonstrated for the class and was able to apply the procedure to construct ten different regular polygons (Figure 3). She used GSP to measure the perimeter and area of her constructed polygons as well as the lengths of the sides. Wendy expended some effort to make the polygons large enough for her purposes because she did not change GSP's measuring unit from inches. The units resulted in Wendy's production of large polygons which necessitated she hold a composite image of the figure in her mind without being able to physically see the entire polygon at once. Her technology tool use provided an opportunity for her to conceptualize regular polygons in a way other than looking at a visual representation. Therefore, the time she invested in the fence problem afforded Wendy a valuable mathematical experience.

Play while engaged with the fence problem

Given that Wendy was largely motivated by performance goals, it is less likely her activity with the fence problem would be playful. However, aspects of her activity were playful. These playful occasions were connected to Wendy's competence and capabilities with the technology tools she used. For example, she quickly learned how to change the color and font of various objects while using GSP. Throughout her experience generating regular polygons, she altered the aesthetic qualities of objects including the measurements she used GSP to represent. She was also able to use Excel to alter the aesthetics of her chosen graphs. Given the similarities of the colors seen in the images of Wendy's work, she chose these visual representations because they were pleasing to her. Since ludic activity may be directly related to pleasure, these are instances of Wendy engaging in activity playfully.

Wendy was able to play mathematically during her engagement with the fence problem. In choosing the number of degrees to rotate a point on a circle about the center Wendy chose numbers which would allow her to construct regular polygons of her choosing. In picking polygons to construct Wendy engaged playfully, but while actually constructing the polygon she did not use the software playfully. Had she chosen to explore other methods to construct regular polygons, her engagement may have taken on a playful characteristic, but since she carried out each construction in the same prescribed fashion, this aspect of her activity was not playful.

There is evidence of her beginning to use the software playfully, however. In the file where Wendy constructed her 9-agon (figure 3.1) she also constructed circles about each vertex of the regular polygon. After constructing a point on a circle to act as the original vertex, she constructed a second point on the circle to use as a point through which she could construct a new circle. As she rotated the original point about the circle to construct the regular polygon, she also rotated the newly constructed circle. In her saved file the circles about the vertices are not obvious at first glance. In fact, when I printed an image of the file, which would fit on one page, I did not notice the circles at all. However, upon subsequent reexamination of her file, she left the circles about the vertices small but clearly perceptible. They are evidence of Wendy engaging with mathematical activity not necessarily related to the fence problem. A reason to leave the circles relatively small was 'that was not what we were supposed to do.'

Whether Wendy produced the extra circles just to see what she could do with the tool or for an aesthetic purpose, using the technology tool playfully, Wendy witnessed a visual representation of a polygon being rotated about an external point, a difficult undertaking for many middle grades students. If her playful tool use led Wendy to develop a conjecture, her technology play may have transitioned to mathematical play. Had she used the software to further play with her new construction she would have the opportunity to investigate other conjectures of her own.

I have stated earlier one way to support a student's technology play transitioning to mathematical play is for a teacher to pose a question related to the student's current engagement. Had I noticed Wendy's construction, posing a question about observations she could make when the second point was pulled around the circle thus changing the size of the circles centered at the vertices could have moved her to play mathematically and develop a conjecture. Also, by posing a question which moved her farther from the original problem posed, Wendy would have an opportunity to experience mathematical activity she initiated and to move towards a goal orientation focusing more on mastery.

Wendy's affective experience during the fence problem

Conceptualizing an individual's affective experience as the transactions between thinking, motives for pursuing chosen cognitive goals, and emotional experiences while engaged in activity proved useful for characterizing playful qualities of Wendy's activity. Since Wendy was often motivated by performance goals, these goals were developed from her interpretation of what I as the teacher was asking her to do. She understood the fence problem had multiple aspects and was motivated to explore rectangles and regular polygons with equal perimeters. As she used the technology tools to investigate the area of rectangles with equal perimeter, the videos depicted a tolerant boredom in her body language. Her exclamations of awe and delight communicated a moderate interest when she altered the colors of the graphs she produced

(Figures 2.1 and 2.2), but this experience did not motivate activity beyond her interpretation of what I was asking her to do.

As she used GSP to construct regular polygons, Wendy's ability to successfully select angles of rotation and efficiently construct regular polygons provided an emotional experience which was productive for her efforts. As she was successfully achieving her goals, her emotional experience supported her motivation to continue to think about the activity. Her extended engagement with the fence problem necessarily provided more opportunities for her to learn mathematics.

Her capability to alter the aesthetic qualities of her work with little effort was pleasant for Wendy also. Her aesthetic play also promoted emotional experience which transacted favorably with her motivation to prolong engagement with the problem. When she changed the colors on Excel charts, GSP objects and fonts and colors of text, her playful activity contributed to her experience by prolonging the duration each object was perceived. Extending the duration spent with a problem can contribute to learning. Perhaps more importantly, engaging in activity with a problem over a considerable amount of time can support productive beliefs about mathematics problems.

Limitations of Wendy's playful engagement with the fence problem are related to her goal orientation. However, her affective experience did support her engagement with the fence problem. The transactions between Wendy's emotional experience, motivation and cognition promoted her engagement. Her ability to make sense of goals, how and why to approach them and her emotional experience supported continuing mathematical activity.

Wendy's engagement with guess my rule

As with other posed problems, Wendy's performance goals largely motivated her engagement with guess my rule. While the class was exploring linear relations without technology tools, Wendy's computational fluency supported her efforts to generate t-charts. When the numerals were integers, she was also able to graph her generated ordered pairs to produce a representation appearing linear on regular ruled paper and on graph paper. She understood the relationships between t-charts, which were generated from the different situations I posed, and the associated graphs more quickly and substantively than many students in the class. Additionally, Wendy had been able to make sense of my demonstrations with the technology tools and apply aspects of these demonstrations to her own work with the software.

In order to thoroughly engage with guess my rule a student not only needed to produce t-charts and graphs, but also find another who would attempt to 'guess' the rule used to generate the t-chart and represented by the graph. Many students used me as the 'guesser' of their rules. My overblown demeanor was largely put on to encourage them to generate rules which were not easily guessed. I had the goal of extending the problem and supporting the students as they explored equivalent expressions producing the same graphed representation and t-chart. Unfortunately, this pedagogical choice also put 'guessing' out of the reach of many of my students. Wendy did not fall into this trap because she had Kathy as a 'guesser' and vice versa. The prior friendship the girls enjoyed influenced their engagement with the problem. They helped each other learn to use the software in order to play the proposed game. Also, they created rules for the other to guess which were reasonable, again showing engagement with guess my rule.

Exemplifying this claim, on March 15, Wendy and Kathy collaboratively generated an Excel file containing two rules (Figure 4). This image depicts a willingness to incorporate integers as well as whole numbers in an effort to engage with the problem. Wendy then went on to choose five of the ordered pairs from the rule on the left to generate the graph in figure 4.1 and inserted this graph as a separate tab in the spreadsheet. The girls had worked together to begin to engage with the problem as I had posed it. They did not attempt to guess the rules but rather experimented with what they could make the software do relative to their goal of generating rules and associated graphs. Given the students had not worked with the computers for more than a week, were growing frustrated with my regular promises to let them work with the computers which did not come to fruition, and had approximately ten minutes to work, Wendy and Kathy had begun engaging with guess my rule very effectively.

x	y=-6x+12	x	y
-8	60	-20	206
-4	36	-10	106
0	12	0	6
4	-12	20	-194
8	-36	30	-294
12	-60	40	-394
24	-132	50	-494

Figure 4

The following day when Wendy returned to the computer, she and Kathy again worked collaboratively to generate a t-chart and a graphed representation of the values (Figure 5 & 5.1). The title of their saved file, “Kathy and Wendy’s Thang!!!,” reflected their collaborative efforts as did the video evidence of their time at the computer. Wendy did not operate the software for the first ten minutes of the session at the computers. Sitting in the chair of the observer was rare for Wendy, but it demonstrated her efforts to work collaboratively with Kathy and engage with the posed problem. Her patience lapsed and Wendy spent the remaining time operating the software as Kathy observed. Although the students had nearly half an hour at the computers this day, these were the only products Wendy saved. The remainder of her time operating the software she explored features of Excel and engaged in communication with other students and me.

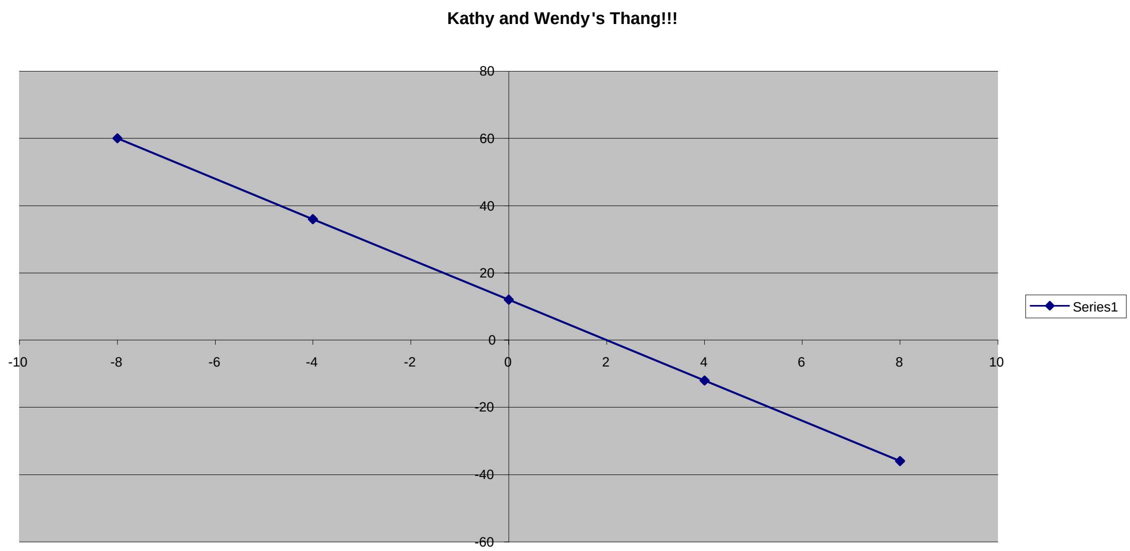

Figure 4.1

-22	11
-20	10
-18	9
-16	8
-14	7
-12	6
-10	5
-8	4
-6	3
-4	2
-2	1
0	0
2	-1
4	-2
6	-3

Figure 5

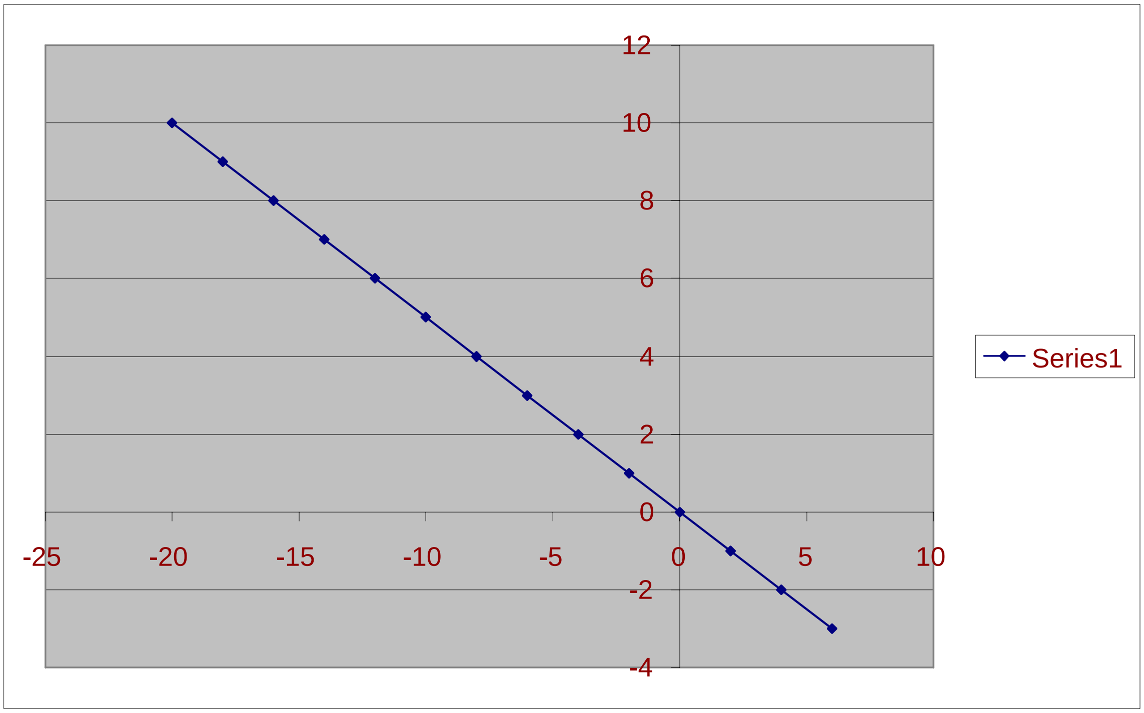

Figure 5.1

The next occasion when students used technology tools was March 18. On this day both Wendy and Kathy spent less than seven minutes at the computer. Classes were changing. As I checked with their next teacher to be certain their tardiness would be acceptable, they worked as my sixth grade students entered the classroom. Working on separate computers at the same time was uncommon for the girls, and Wendy had quickly generated a t-chart and graph (Figures 6 and 6.1). She went on to try to help Kathy generate her chart. As Kathy struggled Wendy suggested procedures to help her generate a chart. When Kathy could not carry these out, Wendy teased her in a friendly fashion by exclaiming, “Chick!” and then reached across Kathy to carry out the procedure herself. Having observed Wendy use a typed formula to pull down a column of independent values, Kathy then generated the column of dependent values on her own. When Kathy was next unable to find the button to produce a graph, Wendy searched along with her. Finally both girls informed me the button they needed to select was not there. I turned on the 'standard toolbar' and Kathy generated the graph of her values (Figure 17.1). Here Wendy has further engaged with guess my rule. Since she had a goal of engaging in mathematical activity with Kathy, she attempted to help Kathy learn the necessary skills in order to generate a rule to be guessed. Thus, by choosing to engage in a collaborative mathematical activity a student, who was largely motivated by performance goals, worked with a classmate to help her learn as well.

x	y
-21	64
-20.5	64.5
-20	65
-19.5	65.5
-19	66
-18.5	66.5
-18	67
-17.5	67.5
-17	68
-16.5	68.5
-16	69
-15.5	69.5
-15	70
-14.5	70.5

Figure 6

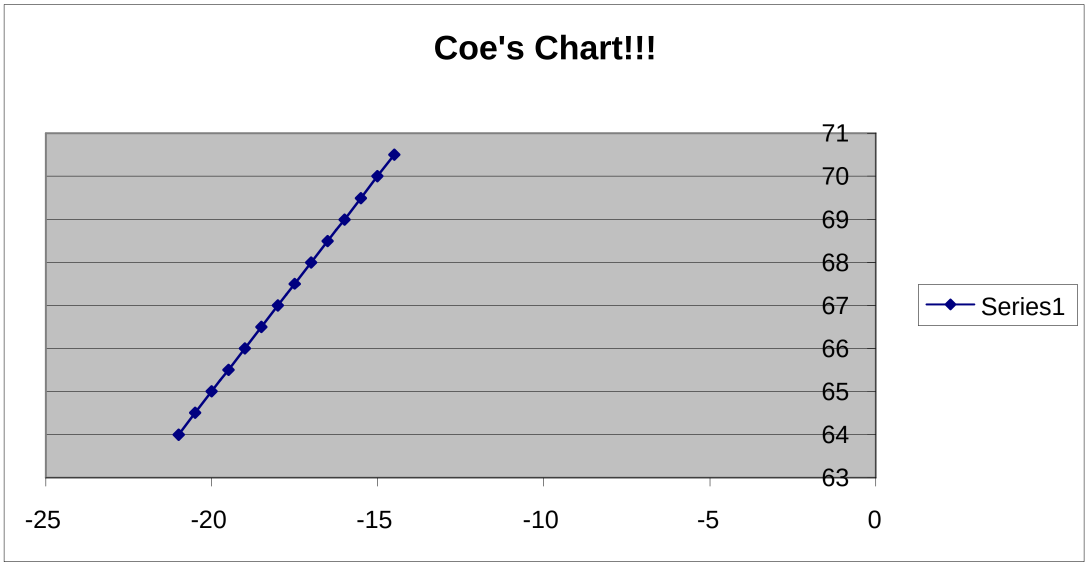

Figure 6.1

The last day Wendy saved her work with guess my rule was Monday, March 21. She produced files represented by the images in figures 7, 7.1, 7.2, and 7.3. The first two figures were generated with a goal to make the 'guesser's' task difficult. A portion of this goal was motivated by my attitude with students suggesting I could 'guess' any linear rule they could make. Wendy spent considerable time trying to get Kathy to guess this rule. She had included only one operation to generate the column of dependent values in an effort to make it easier to 'guess.' Thus, she was motivated to engage in guess my rule collaboratively with Kathy. During their activity Kathy offered a sarcastic guess, "x squared times 7 divided by 2," to Wendy's rule after Wendy had previously mentioned it was "just x times … (pause suggesting, ahhh, come on; it's easy)." Wendy did not catch Kathy's joke instantly, but briefly thereafter when she did get it, she was slightly amused. Rather than disengaging she created the file represented by the images in figures 7.2 and 7.3. Here Kathy did not try to guess Wendy's rule and at my prodding Wendy generated the third column of values dependent on the column labeled "x." She did not focus on mathematical activity for the duration of the video taped segment. Nor did she share the computer with Kathy and attempt to guess a rule she created. However, she did engage in mathematical activity which could have been significant for her thinking about relations and their graphed representations on this occasion.

x	y
-32	-147.2
-29	-133.4
-26	-119.6
-23	-105.8
-20	-92
-17	-78.2
-14	-64.4
-11	-50.6
-8	-36.8
-5	-23
-2	-9.2
1	4.6
4	18.4
7	32.2

Figure 7

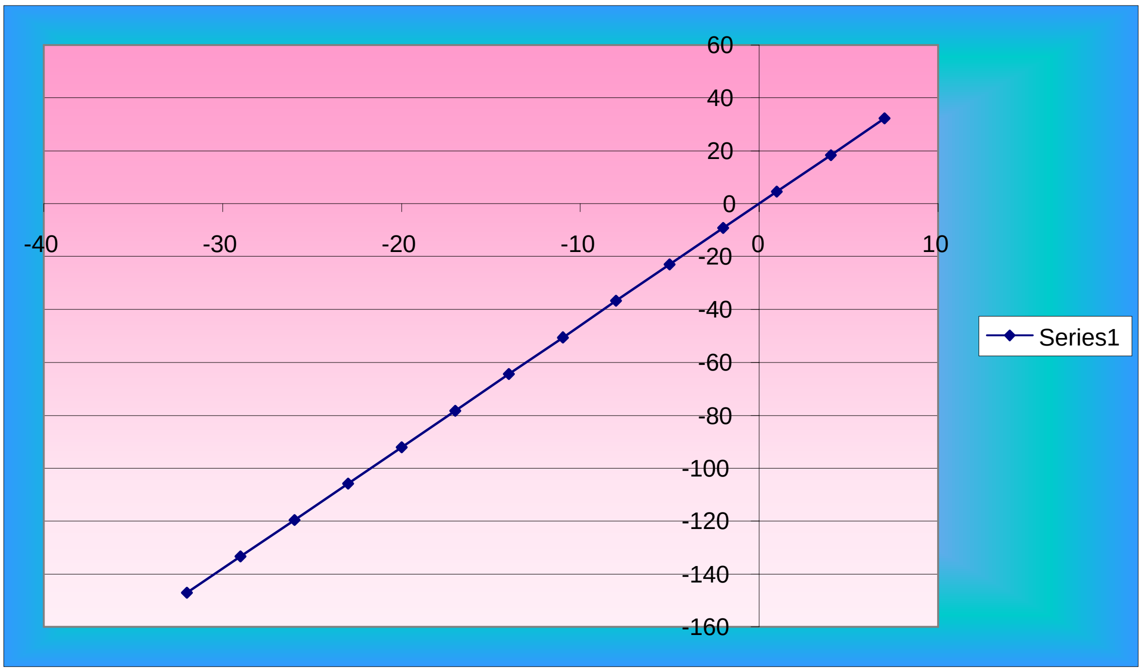

Figure 7.1

x	y	
-20	-98	121
-17	-83	103
-14	-68	85
-11	-53	67
-8	-38	49
-5	-23	31
-2	-8	13
1	7	-5
4	22	-23
7	37	-41

Figure 7.2

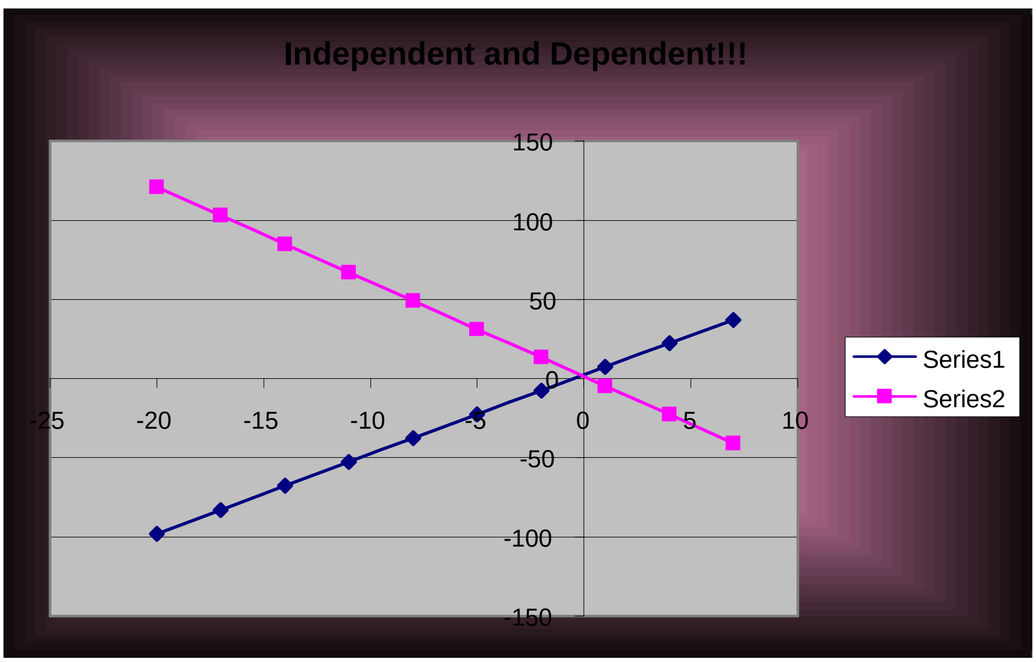

Figure 7.3

Use of technology tools

While engaged with guess my rule, Wendy again used the technology tools effectively. She had observed my demonstrations when I had ‘filled down’ to complete a column of a t-chart and she chose to use the software in such a way, consistent with her engagement with the fence problem. She enjoyed the efficiency with which she could complete an aspect of her determined task, aligning with her performance goal orientation. She used this procedure on potentially every t-chart she generated during the span of the videos. Also, she tried to help Kathy learn how to 'fill down.' Wendy used Excel to create a graphed representation of at least some aspect of every t-chart she saved. For each graph inserted into a sheet, Wendy first increased its dimensions to fill the blank portion of the sheet. When she realized I was not going to criticize the students' efforts to customize their work products and in fact offered verbal commendations to students on several occasions, Wendy gave more attention to her graphs' aesthetic appearance.

Another feature of her technology use was Wendy rarely relinquished control of the computer. When she did give up control, it was typically prompted by my reminders to students they should all share the computers. Also, there are several instances when Kathy was operating the computer and Wendy reached past her because she was not efficient enough for Wendy's preference. Although other students in the class seemed to be willing to spend some time observing their peers at the computer or just sitting around, Wendy often appeared uncomfortable when she was not using the tools. She had demonstrated a preference to be in control of mathematical activity if she was going to engage with it. This control was manifested by her performance goal requiring she know what she was doing in order to perform in such a way as she thought was expected. When she was not in control of the tool, she could not be certain of what was going to happen and thus if she would make any progress towards her goal. Therefore, her goal orientation made it more difficult for her to observe the activity of others.

Play while engaged with guess my rule

Wendy began attempting to play guess my rule from the onset of her efforts with the computer. She attempted to help Kathy learn how to use Excel in order to produce t-charts and graphs. This action exhibited her recognition if she was going to be able to hang out with her friend and be viewed as 'doing what she was supposed to,' then she needed her friend to be able carry out the necessary procedures. She also engaged with guess my rule playfully by attempting to produce rules Kathy would be able to 'guess.' Early as the girls worked to learn how to play guess my rule they experimented with familiar numbers. Regarding figure 6 as not representative of a rule anyone was intended to 'guess' given the time it was created, figure 7 represented the file Wendy first generated in order to be a rule no one could 'guess.' Since I had postured so ridiculously as being able to 'guess' any rule they made, after Kathy could not 'guess' the rule , Wendy challenged me to guess her rule. I scanned the table and thankfully saw the integers –92 and –23 in the dependent column. Realizing the y-intercept had to be zero since Wendy had produced a graph, I told her the rule was "y equals 69 over 15 x". She and Kathy both quickly told me I was wrong. Uncharacteristically humbly I asserted I was pretty sure I was right. Wendy and Kathy explained Wendy had used Excel to multiply 4.6 and each independent value to generate the right column of figure 7. I then asked what 69 divided 15 equaled. Each quickly conjectured the quotient would be 4.6 and then Wendy used Excel to check the division. Thus by playing with guess my rule, the girls witnessed equivalent expressions in a context they developed.

It could be assumed since Wendy used Excel to generate t-charts and graphs so efficiently she was using the tool playfully. Her actions to 'fill down' the columns do not constitute using the tool playfully. They made her efforts to generate t-charts and graphs more efficient but were not playful. On the other hand, her choices for t-chart values and rules exhibit engaging in mathematical activity playfully. In the files Wendy saved in which she and Kathy were learning how to engage with guess my rule she generated independent columns by adding whole numbers with which they were familiar. Then, she progressed from examples where multiplication and addition were used to generate the independent columns (figure 4) to an example where multiplication and division were used (figure 5, she multiplied by negative one and then divided by two). These instances of mathematical activity are playful because she determined the values for the rules. The t-charts she created reflected her numerical interests at the time and the operations she wanted to have Excel perform.

When Wendy progressed to include non-integer values in her work (see figures 6 and 7), again she engaged in activity playfully. She pursued her desire to find out what t-chart would result if she added 0.5 to successive 'x' values and then added fourteen multiplied by six and finally added one to each. Her last t-charts were created with each successive 'x' value produced by adding three to the previous. As described above she multiplied by 4.6 to produce the 'y' column in figure 7 and produced a rule Kathy could not 'guess.' I then provided a different rule, urging the girls think more about relations. Figure 7.2 represents Wendy's efforts to engage in mathematical activity playfully, but within tighter bounds. Instead of continuing to play with non-integer values, Wendy chose only integers for her 'x' values but also used rules with only integers, multiplied by five plus two and multiplied by negative six plus one for the center and righthand column, respectively. She modified her activity in order to continue to 'find out what will happen if,' but kept the values and rules within numeric boundaries she was comfortable with.

Wendy's affective experience during guess my rule

While working with guess my rule, Wendy displayed a desire to make sense of her work on the computer and also to have her efforts validated within the context of the problem. For example, less than ten minutes into class on March 21, Wendy wondered aloud, "Why is there not a zero there?" No individual attended to this question and she continued to be focused on her work at the computer until I stopped the entire class one minute later to show everyone the work of two other students. She reluctantly looked away from her computer and listened to me 'talking at' the class for nearly five minutes. She then returned to her efforts at the computer. She made adjustments to her file, and in the final version of her work, viewed in the video, a zero is present.

This instance exemplified Wendy's affective experience with guess my rule. Often she maintained her chosen goal during distraction and effectively returned to activity once the distracting event was over. The regulation of her motivation does not signify her goal orientation. The fact she pursued goals reflecting 'what she thought she was supposed to do' does signify her performance goal orientation. Commonly when she achieved her academic goals, Wendy engaged in largely social activity. This choice was directly related to an inability to play with Kathy and guess each other's rules. Early as the girls worked together to learn how to engage with guess my rule Wendy exhibited an energetic, interested focus with the context. Having Kathy along for the ride added to her pleasing emotional experience and motivated continued thinking about linear relationships.

As their activity progressed Kathy engaged less with Wendy's efforts, specifically she could not or did not care to 'guess' Wendy's rules. This change in activity was problematic for Wendy since she desired validation with her work; a motive aligned with her performance goals. As an example, on one occasion I discussed the individual activity of the participants with the small group. As I moved to another area of the classroom, the four students started to talk socially. After less than 30 seconds, they returned to activity with the computers, mainly improving the aesthetic qualities of their files. At this time Wendy turned to Kathy and gave her hints so she could guess her rule. This act was a way for Wendy to have her efforts validated. However, since Kathy's response was not aligned with Wendy's goals, she did not experience pleasant emotions. Wendy did ask me to 'guess' her rule, thus remaining engaged with guess my rule at some level. However, if Kathy had attempted to 'guess' her rule, Wendy's affective experience would have been more powerful for continued engagement with mathematical activity.

Walt

Walt's engagement with the fence problem

Walt began the fence problem by working with the rectangle aspect of the question. He understood this portion of the problem. His work to determine different rectangles with a perimeter of 100 and to find their area while working at his desk was consistent with other members of the class. Walt reproduced my introductory demonstrations on his paper and graphed ordered pairs after my prodding.

When the class turned to GSP to further their work with the fence problem, Walt engaged with the problem. He then attempted to create a regular polygon. This goal was not satiated as seen in figure 8. He experienced perturbation when he realized all the sides were not the same length. Rather than fix the polygon, Walt equilibrated by engaging with GSP to find out what he could do with the software, thus providing himself with activity he deemed interesting.

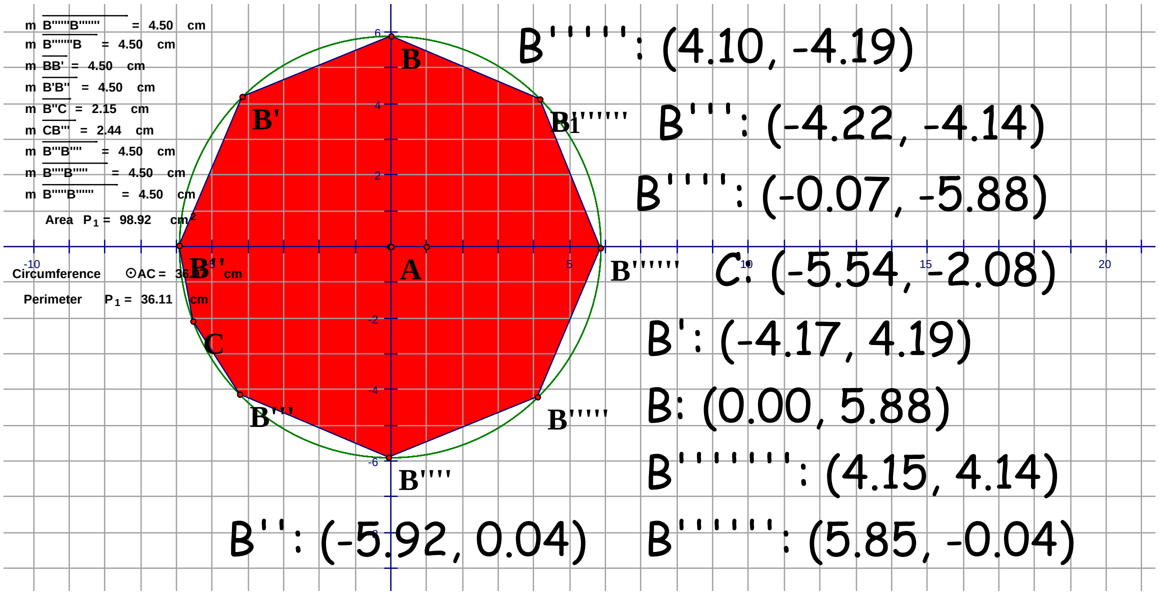

Figure 8

After constructing what was to be a regular octagon[3] (figure 8), Walt used GSP to apply a coordinate system. He then situated the center of the circle at the origin. He aligned vertices of his regular polygon on the axes. Further, Walt labeled the vertices with ordered pairs. He no longer engaged with the problem I posed. Instead he engaged in activity of his choice. This occasion using a technology tool represented Walt's most focused engagement within a range of activity I believed may be valuable for his learning of mathematics.

Use of technology tools

Walt's actions with GSP coincide with his reports of how he learns to use new technology. During an interview when we were talking about technology and how he uses it, Walt explained to me when he gets a new video game, his preferred technology experience, he usually "plays around with the different buttons" to see what effect each will have. His activity with GSP had a similar characteristic. After producing a polygon different than he intended, Walt began to choose different options from GSP's menus.

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[3] He used the point on the circle generated by GSP as a ninth point on his polygon.

He understood from previously using GSP in order to choose options from the software's menus, particular objects in the sketch must first be selected. Having selected different objects in his file, Walt then scanned available options in the menus. With what appeared to have little systematic focus, Walt chose various options and then allowed the results which were pleasing to him to remain. Those outcomes which were not as appealing were deleted or undone with GSP's edit menu.

Play while engaged with the fence problem

Walt's actions described above illustrate his use of the software. His activity with GSP had a playful nature, term it technology play. He engaged with the technology playfully as he found how to coordinatize his construction. When he used GSP to display the ordered pairs for the vertices of the polygon, he again played. Each of this actions are evidence of play as Walt was using the software as he chose with no particular end result in mind. This playful use of technology may lead to mathematical activity. If Walt's activity provoked perturbation he could develop a conjecture and attempt to prove it or find a counterexample. As the instructor I could have posed a question about his work which may have supported his engagement to transition to mathematical play. I did not capitalize on such an opportunity.

Walt's technology play coincided with activity closely related to or indicative of original mathematical activity. He used GSP to focus his engagement. The numerous options available on GSP proved valuable for his interest and motives. Although he saved few files, the videos showed Walt using GSP freely and with his own intentions. The functionality of GSP allowed Walt to feel successful in his efforts to use the tool. Particularly, the microworld GSP offers a user once a polygon is generated was appealing to Walt. There are a number of actions a user can perform simply by picking something deemed interesting. This aspect of the software facilitated Walt's play and worked well as a motivation for Walt to continue to engage in mathematical activity with activity that could potentially become mathematical.

Walt's affective experience during the fence problem

Walt's playful engagement with the technology tool influenced his affective experience productively. The video data and my field notes during the time Walt worked with the fence problem do not show evidence of Walt exhibiting intense excitement or passion for his work. However, his focused attention, observed as he used GSP to approach his goals, supported Walt's experience. His goals could be interpreted as enjoyment-seeking in nature as evidenced by his actions. He animatedly tried to entice the girls' attention when he had produced an object he liked. Also, he remarked aloud to the computer on occasion when he produced a pleasing object.

Although his goals were not directly related to the fence problem or a particular mathematical goal and were more focused towards finding out what he could make GSP do, this activity allowed opportunity for Walt to engage in mathematical activity. In figure 8 he generated representations of measurements in an obligatory use of the software. He also generated a number of other elements in this figure as he played with GSP to find what else he could make it do. During this time, his emotional experience was pleasant or stable and calm. Walt's further play with the software was motivated by a desire to find other things GSP could do which he found interesting.

By this point in the year Walt realized he could maintain a comfortable standing as a student without exerting a great deal of effort to solve a posed problem. Walt's comments during our final interview aligned with the performance avoidance goal orientation I ascribed to him. He openly explained if a problem was hard for him, he typically gave up quickly. Thus not progressing with the fence problem as rapidly or to the extent of his classmates did not adversely impact Walt's affective experience. However, since he did enjoy productive emotional experience while playing with GSP he was motivated to continue his engagement with the tool. This occasion may not have led to a great deal of mathematical activity, but it did create a potential for future engagement with GSP and opportunities to learn mathematics.

Walt's engagement with guess my rule

Walt's engagement with guess my rule differed from his engagement with the fence problem. First, during the two weeks when students rarely used computers as we were working to develop conceptual understanding of linear relationships, Walt and I clashed several times. His conduct in the classroom had been unacceptable several times and I had asked him to leave the classroom on at least two occasions. Additionally he and one of his friends found themselves in trouble with the administration after mooning their baseball teammates. At this time Walt also was working hard to secure his starting position on the baseball team and this effort seemed to be the main focus of his school experience.

Adding further complications, the content we were discussing in class was difficult for him. He struggled to explicate relations depicted by scenarios we explored as a class (Cramer, 2001). He also struggled to use a determined relation to find other values satisfying the relation. He routinely avoided working with the linear and non-linear situations other members of the class worked to understand. These actions were not surprising given Walt's goal orientation. He had previously demonstrated a 'comfort' to disengage when the content became difficult for him. While other students used Excel to generate linear relations, Walt's engagement with guess my rule was superficial and he produced no saved files.

Use of technology tools

In this case technology tools hindered Walt's efforts to solve a problem or to find a way to engage with the content. Walt's engagement was primarily grounded in his choice to preference his social goals for academic goals. Regardless, the technology tools did not help him to learn more mathematics. In fact, the technology tool likely got in the way of his potential to develop understanding of content. One reason for this occurrence is supported by his comment "my computer is sped." Here Walt was pointing out he did not think his computer was as good as his classmates' (he was correct). Also, he was providing a defense for his inability to engage in mathematical activity with Excel or the computer, in general.

As the students began to incorporate the computers to support their efforts to understand linear relationships, Walt's experience became less productive for his learning of mathematics. He had difficulty using Excel to generate a sequence of independent values. He also struggled to use Excel to produce the associated dependent values. He was able to use Excel to graph the values once the columns were generated. Part of his difficulty stemmed from his inability to discern how to play with Excel. While using GSP, Walt had been able to make the tool do things he found interesting. This was not the case with Excel and is directly related to the differences in the structure each program uses to operate. When using GSP, he only needed to select objects and then choose an available option to get the tool to do something. There was a wide array of choices for Walt in this situation. However, Excel does not function in this fashion. The necessity to produce numeric values and then to use formulas in particular cells to operate on the chosen values required more understanding of how to use the tool and allowed for less freedom and playful engagement. Therefore, Walt's technology use was limited. As described below his affective experience was also not productive for his use of Excel.

Walt's affective experience during guess my rule

Walt's affective experience was largely productive for his engagement while using GSP. This was not the case with guess my rule and Excel. Walt was not able to make the software do what he wanted it to do or to do something he found interesting. As these occasions amassed, Walt responded in several ways.

On one occasion while walking from his seat by the door on the south wall to the computers on the north wall to begin working, Walt purposely walked into various pieces of classroom furniture moving each of them from their location. Just before arriving at the chair, where he would sit to work at the computer, he kicked another student's backpack launching it more than a foot from where it rested. He then yanked the chair out and dropped into it. Having witnessed his path to the computer and his actions along the way, I chose not to scold him for his actions because it was apparent to me I would not improve his experience by interacting with him. I hoped he would regulate his emotions and begin to use Excel to develop a rule a classmate could then attempt to 'guess.' This hope was not realized.

Immediately upon seating down he ordered Faith to be his partner. She looked at him incredulously with a gaze suggesting, 'If you want me to work with you, you need to ask me nicely.' Dejectedly, Walt began to use Excel. He did not make substantive progress towards generating a t-chart. His emotional experience had had a debilitating influence on his motivation to engage in mathematical activity.

Struggling to use Excel to approach the mathematical concepts related to guess my rule motivated Walt to engage in activity of a non-academic nature as well. Since pursuing academic goals proved difficult for Walt he chose to pursue his social goals instead. For Walt these goals involved acting in such a way as to be perceived as funny or cool by his classmates. He would strike the escape key on the keyboard in order to make the computer produce an error noise. Then, he would reach across to Faith or Wendy's computer and attempt to get their computer to make the same noise. During periods of time while other students were engaged with guess my rule, Walt was observed banging the keyboard like a piano or singing an alphabet song as he typed each successive letter. These actions are evidence of his performance avoidance goals. Since he was not able to engage in academic goals, Walt chose to pursue his social goals.

As another example, on an occasion when I was working with Kathy and Walt was within arms reach, he chose to repeatedly open and close the cd tray. He exhibited this action in such a way to see if I was observing him and would tell him to stop. In the past he had been motivated to act to gain such negative attention from his teachers. I took my cue to respond from the girls. Regularly they ignored Walt and chose not to engage with his activitiy to distract their chosen engagement. I, also, chose to ignore his actions in this case.

Walt's lack of progress on the problem I posed was largely influenced by his debilitating affective experience. The contributing factors include the rocky relationship Walt and I experienced over the previous days, his lack of understanding of the mathematics in question, and most critically his inability to use Excel productively in this context. Therefore, Walt was not able to make substantial progress with guess my rule or to play with the technology tool or mathematics in general.

The varied obstacles to Walt's experience with guess my rule described above show affective experience can hinder playful engagement. My second question focused on the influence play would have on student's affective experience. Walt's playful activity with the fence problem was related to the technology tool and his productive affective experience. Here Walt's affective experience was such that mathematical play was not possible. Therefore, it becomes clearer how essential the reciprocal relationship is, namely the influence affective experience has on playful engagement. Since his emotional experience was as described he was not able to play in this context. Wherever an individual's boundary may lie defining affective experience conducive to play or not, Walt's was in the region where he could not play. His emotional experiencehindered his motivation and his thinking about the content. Thus affective experience was the primary contributor to Walt's choice not to engage academically during this portion of our course, but rather to choose to approach his social goals.

Faith

Faith's engagement with the fence problem

As with many of the problems posed during the year, Faith engaged with the fence problem in an effort to understand the problem, to develop a plan to solve the problem and to work towards a solution. She shared her ideas with classmates both in whole group discussions as well as in exchanges with small groups of her classmates, aligned with her mastery goal orientation towards school mathematics. She explored different rectangles with perimeter of one hundred as well as attempted to construct regular polygons with perimeter of one hundred.

Like many of her classmates Faith worked to construct regular polygons with GSP. She first made an attempt to construct a regular heptagon as seen in figure 9. Rotating a point on the circle about the center of the circle was consistent with my demonstration of a way to use GSP to construct regular polygons. Her choice of a fifty degree angle for the angle of rotation produced the polygon seen in figure 9. Her measurements of the lengths of each side provoked perturbation because she recognized the values should all be equal.

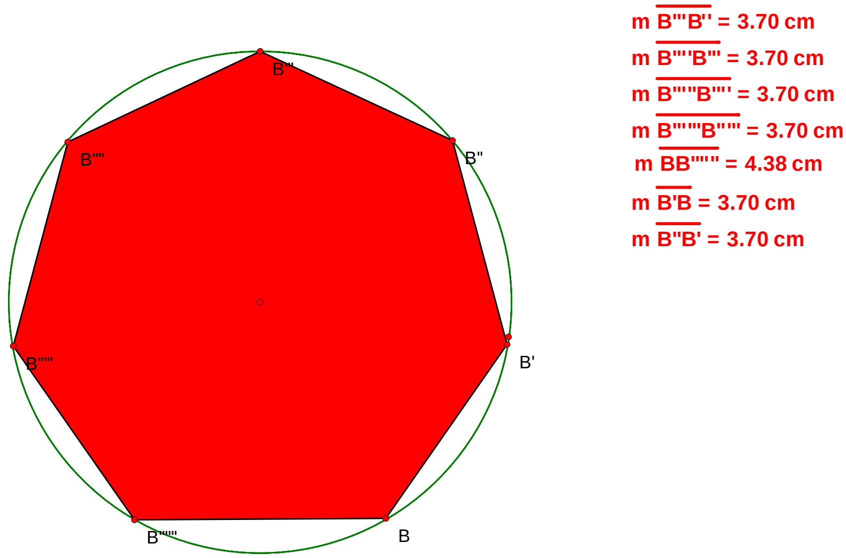

Figure 9

She knew the sides of regular polygons should be congruent and attempted to alter her construction to address this error. Her effort which she titled “fixup7-gon” is seen in Figure 9.1. Again she did not construct a regular polygon and realized a mistake with her work. Having not changed the angle measure which she used to produce the successive images of the point on the circle, she was not able to generate a polygon with congruent sides. Again Faith recognized an inconsistency with her product and her goal to construct a regular polygon. This recognition is evidenced by her construction, Figure 9.2, in which she chose to alter the number of degrees in her angle of rotation. For this effort she chose 25 degrees and again experienced perturbation when she measured the sides of the polygon and realized they were not all congruent. Her chosen file name, “*Faith*don’t know” represented she was not sure how to correct the error of her construction. All the files associated with the images in figures 9, 9.1, and 9.2 were produced on the same day.

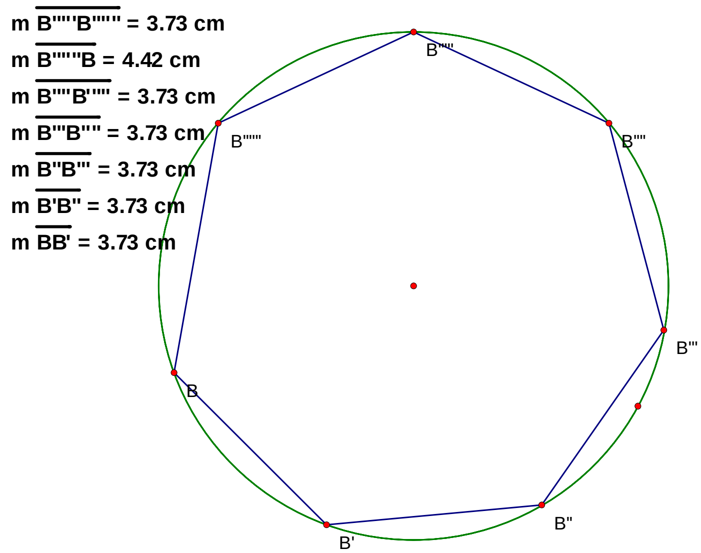

Figure 9.1

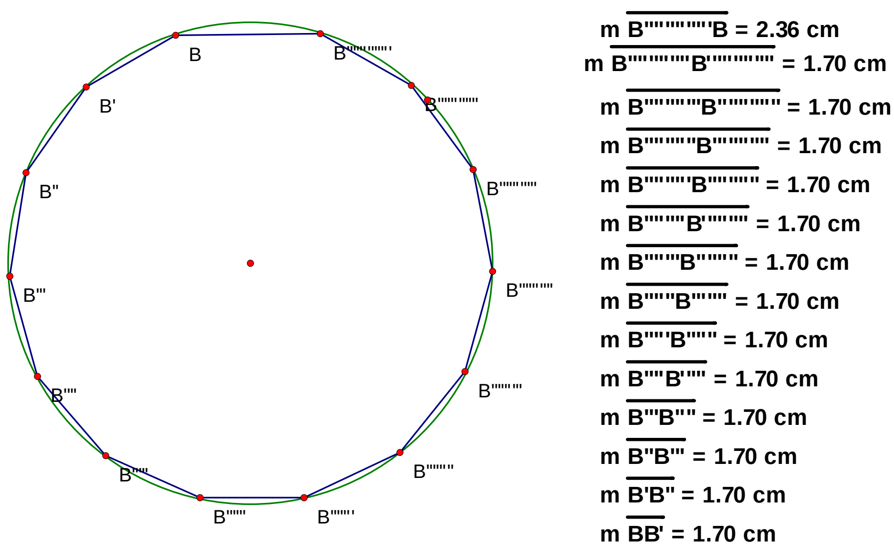

Figure 9.2

On January 25, Faith consistent with her mastery goal orientation, in an effort to equilibrate chose a different direction for her work with the fence problem. She had previously explored different rectangles with a perimeter of one hundred by making a table of values on her paper. On this day she chose to use GSP to construct a rectangle (Figure 10). Other students chose to continue exploring regular polygons in the context of the fence problem. Having been introduced to GSP by approaching the problem of constructing a square, Faith was able to use her prior experience with the software to construct a rectangle. After several attempts over the course of nearly twenty minutes she produced the image in figure 10. She did not measure the sides of the rectangle in an attempt to relate her work to the fence problem, but instead attempted to produce a rectangular parallelepiped.

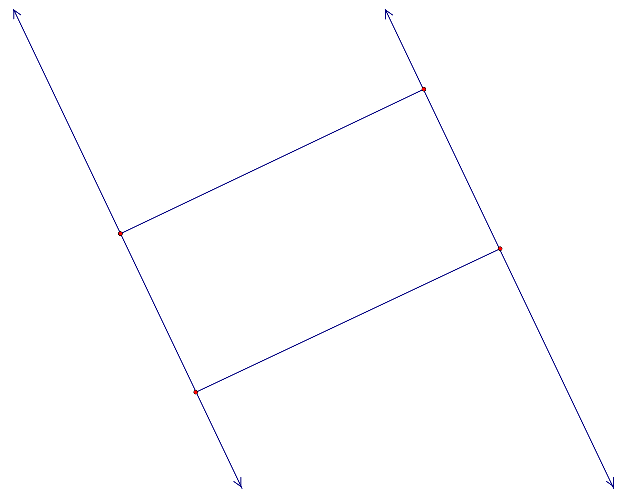

Figure 10

The following day Faith returned to her earlier efforts to construct regular polygons by rotating a point on a circle about the circle's center. Faith's attempt to construct a regular pentagon is seen in figure 11. Again she did not construct a regular polygon. In this instance she chose to rotate a point on the circle 75 degrees about the center. Given the fact she did not attempt to make the polygon larger in order to find an approximation for the area when the perimeter was one hundred, she understood her construction was not sufficient for her goal to generate a regular polygon.

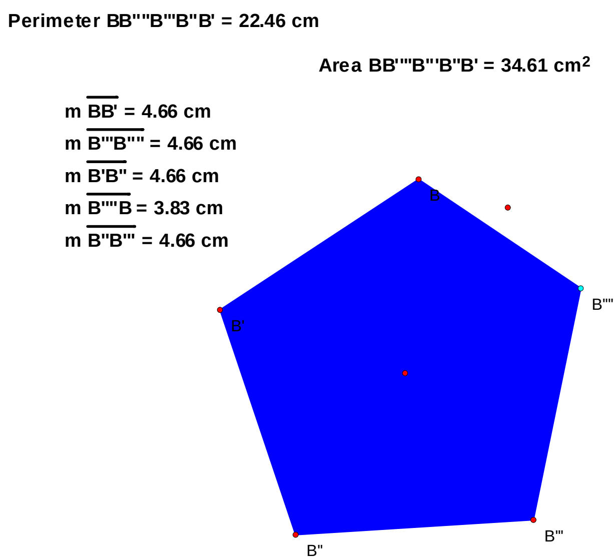

Figure 11

Rather than quit given her inability to resolve this perturbation, Faith instead chose to pursue a different goal. I had encouraged all the students to use Excel to make charts in which they entered the dimensions[4] of the various regular polygons constructed as well as the approximations for the areas of these polygons. Faith reoriented her efforts to approach such a goal. Within fifteen minutes of saving her work seen in figure 11 she had produced the table seen in figure 11.1. Although there is no evidence of her finding the area for the 18-gon she listed in the table, she did use Excel's computational tools to determine the side lengths of the equilateral triangle and square with perimeter of one hundred. The class ended as she was entering the formulas to find the side lengths. She would have continued with this activity if more time had been available.

POLYGONS DEMENTIONS A= AREA

[4] As a class we worked with rectangles first and used the term dimensions. I decided to stay consistent with the language even though for the regular polygons other than the square the dimensions and the lengths of the sides are not the same.

REGULARS		
traingle	33.3333333	
square	25	
pentagon		
hexagon		
7-gon		
octagon		
9-gon		
dectagon		
12-gon		
18-gon		788

numbers are getting biggeer/
think about shape and

Figure 11.1

The following occasion, February 2, upon which Faith saved her work, she again used Excel. This instance shows her using the software's computational tools and its ability to fill a formula into successive cells to generate the table seen in figure 12. Further she goes on to use Excel to generate the graphs of this data seen in figures 12.1, 12.2, and 12.3 and described them by typing "THE CHART RELATES TO THE AREA AND THE DATA THAT WE'VE FOUND." Thus although it seemed she was not successful in her attempts to engage in the problem and construct regular polygons with GSP, she was able to use Excel to explore the rectangle aspect of the fence problem thereby remaining engaged with mathematical activity.

Her mastery goal orientation offered a motive for continued engagement. Faith chose another aspect of the fence problem and used the software to pursue her goals.

Dimensions of the rectangles		AREA
5	45	225
6	44	264
7	43	301
8	42	336
9	41	369
10	40	400
11	39	429
12	38	456
13	37	481
14	36	504
15	35	525
16	34	544

Figure 12

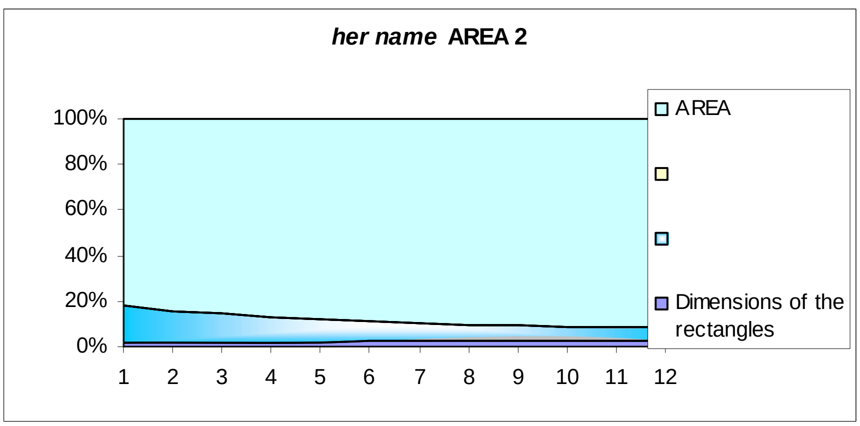

Figure 12.1

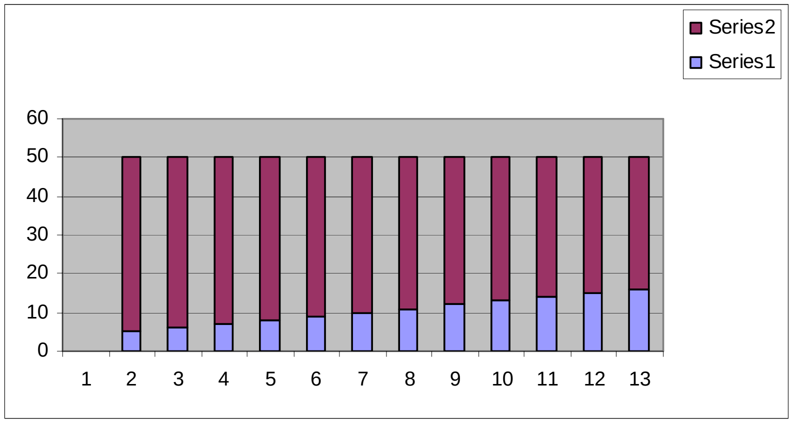

Figure 12.2

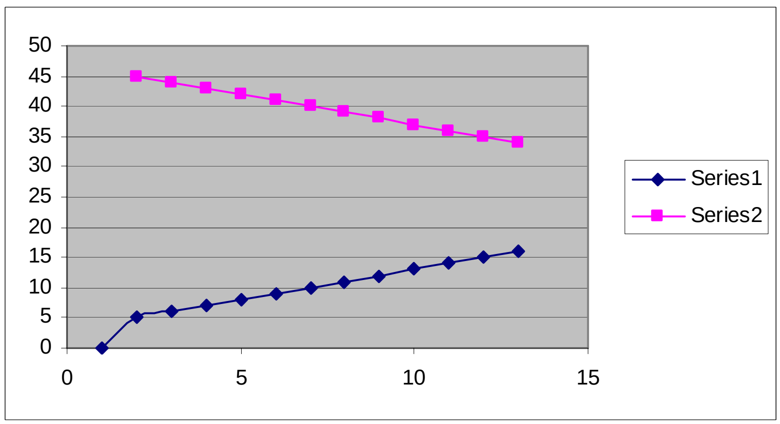

Figure 12.3

Use of technology tools

Faith's desire to use technology tools focused her goals for engagement with the fence problem. While using GSP to construct regular polygons with a perimeter of one hundred, she did not relate the angle of rotation of a point on the circle to factors of 360 in order to construct a regular polygon. Although she attempted to construct regular polygons on several occasions (figures 9, 9.1, 9.2, and 11), she was not able to resolve the perturbation provoked when one side of the polygon had a different length than the others. Instead of quitting, Faith chose to use GSP to pursue an alternate goal. Thus the opportunity to use technology facilitated her continued engagement with the fence problem.

The opportunity to use Excel allowed Faith to continue to engage with the fence problem. In fact, Excel provided Faith an oasis she could visit and have time to equilibrate before returning to the desert. By choosing to build a table of dimensions for rectangles with perimeter of one hundred, an action I had demonstrated during whole group instruction, Faith created an opportunity to think further about the problem. Also, the production of the graphs seen in figures 12.1, 12.2, and 12.3 opened a potential opportunity for further mathematical understandings. All in all, Faith was able to move from a tool she could not use as she wished to one she could. Her successful use of Excel led her back to GSP for further attempts with the software.

Play while engaged with the fence problem

Faith's efforts to construct regular polygons with perimeter of one hundred do not represent a playful use of the technology. I had suggested this method to the class. Also, her efforts to construct a rectangle with GSP do not evince mathematical play. She played with the software and used her mathematics knowledge to produce the construction, but she had a definite product as a desired result for her work. Thus, her play was not wholly mathematical, but rather her activity with the technology was playful as she approached her goal. Her work with her constructed rectangle as she attempted to create a parallelepiped is an instance of technology play and mathematical play meshing together. The microworld GSP afforded allowed Faith to play with the mathematical ideas associated with representing a three dimensional object on a two dimensional surface. Additionally she was using GSP in such a way as to see what else it would let her do. She did not focus on constructing segments along particular parallel lines, but rather chose to pull segments and see what she could represent. This occasion is evidence of both mathematical and technology play because she was attempting to find out what the tool would allow her to do within the confines of mathematics, hence her efforts were rule-bound, but her goal was to play with the representation. Her technology play led to mathematical play and vice versa. Thus, engaging in activity playfully promoted further engagement which also had a playful characteristic.

Faith's activity exhibited technology play when she produced the graphs seen in figures 12.1, 12.2, and 12.3. She used the area graphing option in Excel with all data highlighted to produce figure 12.1. For the other figures she selected the columns containing the various dimensions she chose and graphed them as she wished. None of these graphs were the option I had told the students to use, XY (scatter). If any of these representations had stimulated perturbation and Faith had worked to equilibrate by conjecturing and exploring the mathematical ideas related to the graphs, then she would have created an opportunity to learn mathematics and engage in original mathematical activity playfully. There is no evidence in my field notes or the videos to suggest these representations were problematic for Faith. In fact, given that she inserted the graphs in a different sheet in her file, I contend she was playing to find out what she could make the software do.

Faith's affective experience during the fence problem

Throughout Faith's work with the fence problem her affective experience was critical to her efforts. When she experienced perturbation producing a polygon different from one she intended, she did not quit in her efforts to engage with the problem. Observations of her emotional experience did not show strong outward expression of concern. In fact, the only occasion on which Faith reacted in a fashion which may be characterized as a expression of strong emotion was in response to a offhanded comment I made. While explaining to a student in the class how he may operate the camera capturing student's work with the technology to learn more mathematics and to help me, I commented only Kathy and Wendy were doing what they were supposed to be doing. At this time Faith was playing with GSP to create the parallelepiped. She spun and in an emphatic tone exclaiming, “I’m doing what I am supposed to be doing.” She then returned to her activity with the software.

At other times while engaged with the fence problem she appeared to remain calm and contemplative of her efforts and seemed to be acting metacognitively. This action can be attributed to Faith’s self-regulation. By maintaining her mastery goal orientation, Faith was able to experience perturbation and not cease all engagement with her activity. Although she did not achieve her original goal, construction of a regular polygon, she was able to equilibrate by engaging with the problem as she redefined it by directing her efforts along a different trajectory of mathematical activity.

Engaging in mathematical activity with a playful orientation is again shown to productively influence a student’s affective experience. Likewise a student’s affective experience furthered mathematical activity. Here Faith’s ability to regulate her affective experience and reorient her efforts towards another aspect of the problem allowed her the opportunity to play with mathematics and technology. Thus she created a potential to learn more about mathematics as well as about using the tool. Had her affective experience influenced her to cease her efforts with the fence problem she would have lost the opportunity to explore mathematics and GSP autonomously. Hence, this occasion provides further evidence to support the value of a student approaching academic situations with a mastery goal orientation.

In addition to Faith’s ability to regulate her affective experience while she engaged with the fence problem, an aspect of her ‘successes’ with engagement can be attributed to her experiences with technology in elementary school. After having chosen Faith as one of the study’s participants, I learned she was one of a handful of students in her grade level chosen to be a technology assistant during elementary school. These students had independent access to technology on a more frequent basis than their peers and assisted their teachers with technology needs in the classroom. Hence although Faith had not used GSP until the year of the study, her earlier positive experience using technology independently had a productive role in her efforts with the fence problem.

Faith's engagement with Guess My Rule

Faith was oft observed remaining in her desk and working independently with the concepts discussed as a class before moving to join the others at the computer during our work with relations. Prior to incorporating Excel into our work, the students developed t-charts and graphs for relations I posed (Cramer, 2001). Also, the students changed these relations to form new t-charts. Faith engaged in activity to produce her original relations more intently and successively than many of her classmates. When the students had the opportunity to use Excel to generate original t-charts with a rule of their choosing, Faith's mastery goal orientation motivated her to spend time planning what she wanted to do with Excel.

On March 15 the video showed Faith manually entering the numerals displayed in the column she labeled as x (Figure 13). Originally I surmised this action with the software meant she had forgotten how to make the computer count, by filling down, since the students had not used Excel for several days. Upon further analysis, I decided she knew she could enter them rapidly and wanted this pleasurable experience when she could display her keyboarding prowess. She entered the numbers with such efficiency that Kathy exclaimed in awe.

X	Y=
10	
15	

20

25

30

35

40

45

50

55

60

65

70

Figure 13

The next day Faith generated the ‘y’ column by dividing each independent value by negative five (Figure 13.1). In this case she used Excel’s ability to ‘fill down,’ thus giving support to my assertion she preferred to manually enter values in the x column shown in figure 13. Having created the table in less than four minutes, she then left the view of the camera and spent time at her desk and with members of her closest peer group. She returned within the next four minutes and used the software to generate the graphs seen in figures 13.2 and 13.3. There is no evidence of Faith asking anyone other than me to guess the rule she had generated or of her guessing any of the rules of Walt, Kathy or Wendy. When she asked for my guess, I told her I thought her rule was “y equals the opposite of x divided by 5.” She explained she used Excel to divide each of the independent values by negative 5. Thus, we had the opportunity to connect back to my earlier ‘talking at’ the class about equivalent expressions in the context of her work. Later she typed the rule in the upper right cell of the table as seen in figure 13.1.

X

	Y=x/-5
10	-2
15	-3
20	-4
25	-5
30	-6
35	-7
40	-8
45	-9
50	-10
55	-11
60	-12
65	-13
70	-14

Figure 13.1

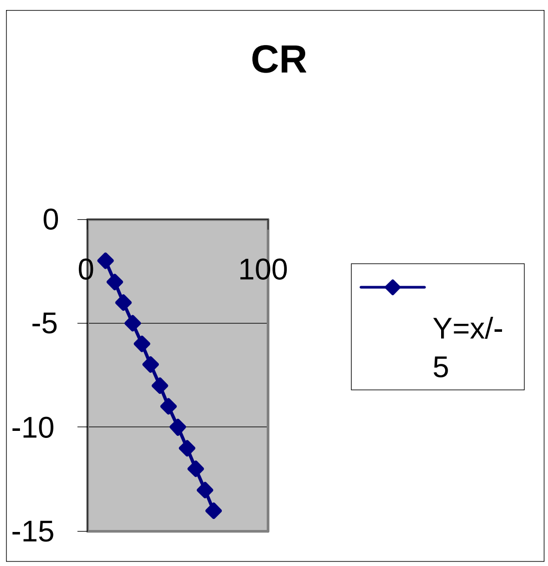

Figure 13.2

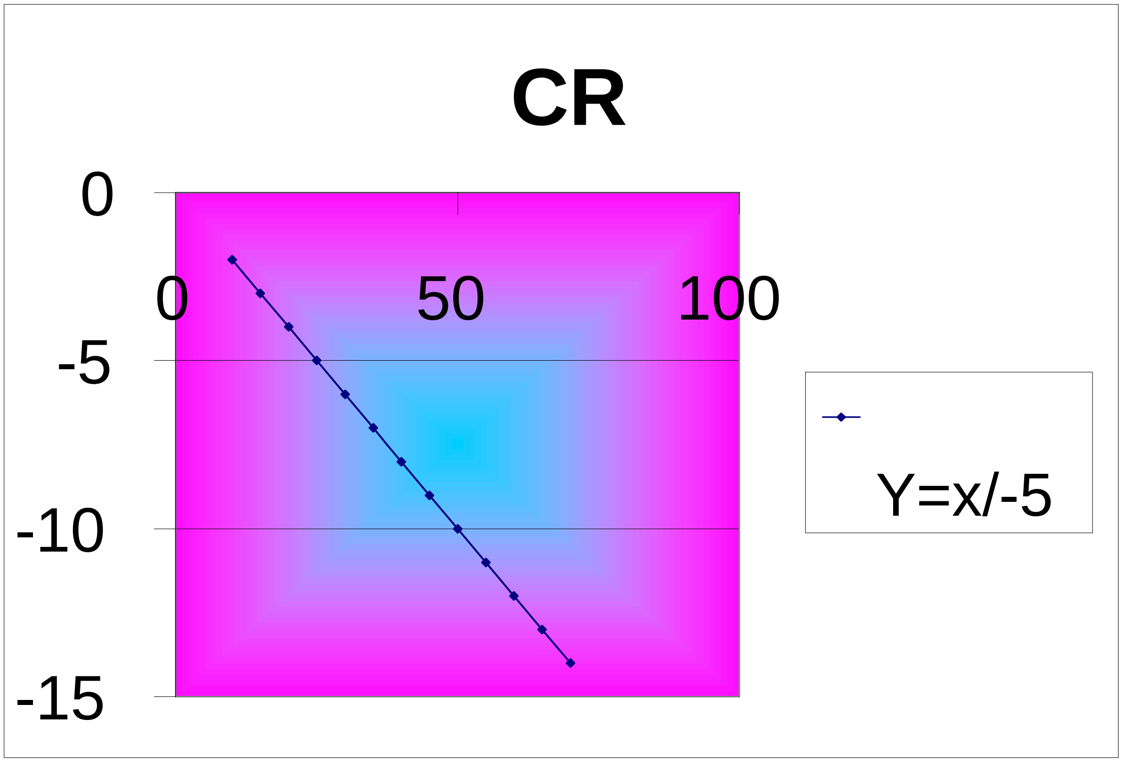

Figure 13.3

Next, her activity to generate a new t-chart and graph for a different rule showed Faith again manually entered the numbers in the independent column, which she labeled r (Figure 14). Originally I surmised she first added .07 to get the second value in the independent column and then added incorrectly to arrive at the third value. Upon further inspection of her work, it appeared Faith was purposely alternating the numbers she was adding to create a pattern she found interesting. By adding .13, then .07, and again to .13 she could generate the pattern in the values seen in figure 14. However, when viewing the video segment where she created this column it is evident she was not computing but rather generating a pattern she deemed interesting. She alternated the 2's and 5's in the rightmost position and consecutively reduced the digit to the left.

R	K
-0.52	-15.52
-0.45	-15.45

-0.32	-15.32
-0.25	-15.25
-0.12	-15.12
-0.5	-15.5
5	-10
12	-3
25	10
32	17
45	30
52	37
0.52	-14.48
0.45	-14.55
0.32	-14.68
0.25	-14.75
0.12	-14.88
0.5	-14.5

Figure 14

She experienced perturbation after she entered -0.5 for the sixth value in the independent column. After thinking briefly and then with an audible "ooooo" Faith equilibrated and decided to type 5 in the next cell. Faith continued her pattern with the 2's and 5's this time increasing the successive values in the tens place. When Faith got to 52, she again decided for a change and entered .52 into her 'r' column. Here, she mimicked her pattern from the beginning of the chart. She also kept her latter patterning consistent with the values preceding by choosing to double the 2's in the 12^{th} and 13^{th} values as she had two 5's consecutively in the 6^{th} and 7^{th} values, her two transition points for her values.

Having constructed the independent column, Faith engaged with the game I had offered. The video evidence supports this assertion since it showed Faith cupping her hand over the portion of the monitor displaying her typed rule. Shortly after entering this formula, Faith filled her formula down the column applying her rule to each of her independent values. She then asked me to guess her rule. She and Walt both told me he had not been able to guess the rule. I requested she provide a graph and she produced the graph seen in figure 14.1. After several moments, I told Faith I thought her rule was “r minus 15.” She disagreed since she had typed -10 - 5 for her formula. Again we talked about equivalent expressions.

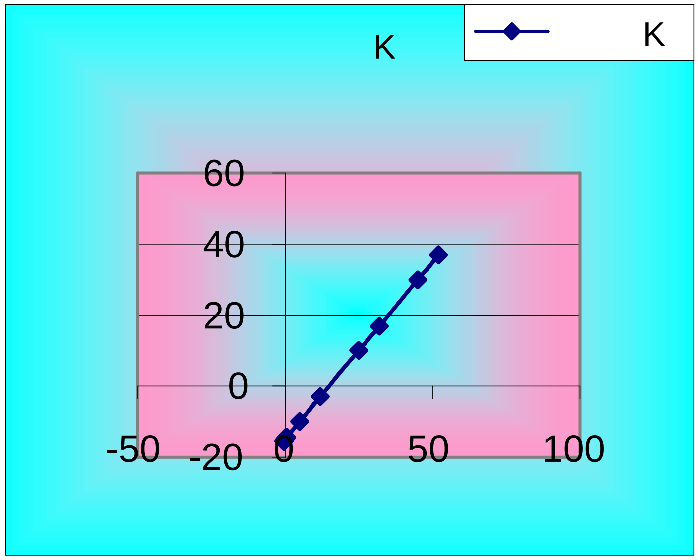

Figure 14.1

Use of technology tools

As I stated above Faith’s engagement with guess my rule generally involved her working independently at her desk before joining other students at the computers. During these occasions, she was observed working with the concepts the class had discussed as a large group. She would then regularly move to the computers and use Excel to follow up with her ideas. The technology tool allowed Faith to engage with guess my rule in a way she would not have been able to experience were the software not included in the course.

An example was in the keyboarding skill she was able to demonstrate. Writing the independent values on her paper did not afford Faith the opportunity to display her skills with computers and inputting data. Hence the experience of using technology tools in this setting provided Faith an opportunity to demonstrate other skills she possessed as well as offered an avenue for her to generate a column of values without having to write them on her paper. In addition to her keyboarding proficiency, Faith was able to use the computer effectively in other respects. For example, upon returning to using the software to engage with guess my rule on March 16, Faith returned to a file that she had saved the previous day. Such an action was not at the disposal of all students. Faith's skills with features of the technology tools afforded her an advantage for engagement with this problem.

Her technology use also allowed her the opportunity to focus her attention on aspects of the concepts under investigation rather than requiring her to attend to the computational necessity of generating the table. Originally, I was comfortable to assume Faith's efforts to generate the table in figure 14 were based on incorrect calculations. My first analysis of this work was supported by my observations of and interactions with Faith when she did not compute with rational numbers with great accuracy or efficiency. Incorporating the technology tools eliminated the need for Faith to attend to the computations and thus allowed her the opportunity to experiment with numbers and operate on them in ways she may not have chosen otherwise. Thus, the software offered Faith opportunities to think about particular numbers and easily view the outcomes of computations in an efficient way. Therefore, her thinking could be focused more substantively on the mathematical concepts relative to the problem as she would not have to attend to the procedural aspects of generating the tables.

Further, Faith's engagement with guess my rule while incorporating technology tools eliminated the need for attention to be focused on the necessary precision required to graph rational number ordered pairs on a coordinate plane. Given my goal to provide opportunities for the students to learn about linear relationships, it was important graphed representations of a set of values form a line. This representation is far less difficult to create by hand if all the values are integers. However, because I wanted students to think about values other than integers, the ability to produce accurately graphed representations of non-integer values was important. Since Faith used Excel to produce graphs of her tables of values, she was able to remove some of the procedural aspects of generating a representation and free her cognitive capacity to attend to other aspect of her experience. Therefore, the incorporation of technology tools provided Faith an opportunity to attend to aspects of the problem she may not have without using the software.

Play while engaged with guess my rule

In addition to providing Faith the opportunity to free her cognitive resources to consider conceptual aspects of this problem, the software provided Faith an opportunity to play mathematically, aesthetically and with the tool. Faith engaged in mathematical activity playfully within the context of her chosen rule (Figure 13.1) and its relation to her chosen independent values. She counted by fives because this choice allowed her to easily generate the set of independent values she wanted to substitute. Then in choosing to divide each of these values by -5, Faith played with the mathematics of this situation. She realized dividing each of these independent values by -5 would yield an integral quotient. She had experience in her previous mathematics classes with whole number computations and by including a negative divisor was able to explore the pattern produced. My observations of Faith's mathematical activity throughout the school year showed her regularly searching for pattern and other relationships in situations she explored. Her search for patterns was particularly prevalent as we developed t-charts during whole class instruction. Faith understood linear relationships had a constant slope and thus rather than compute to complete t-charts I presented to the class, she would look for a pattern in the dependent values and use the pattern she discerned to complete the tables. Faith's production of pattern in figure 13.1 represented her playing with the mathematics of linear relationships as well as with the specific values chosen in order to produce the t-chart.

Faith also used the technology tool playfully. From the point when she asked Kathy and Wendy, "Which chart to I pick?" Faith began to play with the software. The video showed her choosing the graph that Kathy told her was the proper one, "XY scatter," but then sizing it to dimensions that she deemed aesthetically pleasing. Here her technology use took on characteristics of aesthetic play, a potential precursor to mathematical play if the aesthetic play leads the student to conjectures which are then attempted to be proven or refuted. As an example consider Faith's insertion of figure 13.2. After choosing the graph style we as a class had been using, Faith began to resize the graph. This action to make the image more aesthetically pleasing could lead to a mathematical conjecture being developed if the play produced a perturbation for the student. Had Faith manipulated the image of the graph in such a way as to alter the values on the axes and/or the slope of the line she could develop a conjecture related to this change in the image when the values in the t-chart did not change. Exploring this conjecture would provide an opportunity for Faith to learn more mathematics of her own choosing.

She produced the pattern of independent values in figure 14 playfully. Choosing to use the pattern of her choice for these values allowed Faith to engage in mathematical activity that pleased her. She was clearly interested in using numbers which were not routine also adding to her playful activity. The file represented by figure 14 represented Faith engaging playfully when she subtracted ten and then five to generate the dependent values. This play is mathematical in at least two respects. She wanted to develop a rule, which was not simple to 'guess,' and thus used two operations. She chose numbers for her rule, which were very familiar to whomever might guess her rule. Thus, she engaged playfully in the problem I had posed by producing a rule accessible to a 'guesser,' but at the same time one she thought was not too easy. Secondly her mathematical activity was playful because she chose values she typically did not operate with proficiently. By operating with these numbers in a context where mistakes were not a concern, Faith played with mathematics. Her play could have lead to important mathematical understandings. One, focused on figure 14.1, relates the graphed representation of a relation and a t-chart representing the relation. Figure 14.1 seemed to represent only seven ordered pairs. However, Faith clearly made more than seven entries in her t-chart. Her playful activity could have allowed her to conjecture what happened to the other pairs and thus increase her understanding of graphed representations in general. If Faith had engaged with guess my rule only as I had suggested and not playfully, this opportunity to conjecture would not have occurred.

Faith's affective experience during guess my rule

Faith's engagement with guess my rule regularly provoked transactions between her emotional experience, motives and cognition promoting continued mathematical activity. If she had a peer to 'guess' the rules she used to generate t-charts and graphs, her affective experience would have improved. Often her emotional experience seemed to signify complacence to engage in mathematical activity, but she did not evince emotions interpreted as consistent with optimal experience. Her independent engagement and goal orientation fostered playful activity as described above, but not having someone to work closely with hindered her efforts. Also, she did not 'guess' rules others generated with any regularity losing an opportunity for emotional experience related to mathematical competence.

I do not intend to suggest Faith's affective experience was debilitating for her activity. As Faith experienced success with her goals, she was motivated to pursue further cognitive activity. Her mastery goal orientation provided motives for this continued activity rather than activity being driven directly by pleasant emotional experience. Thus if a student is motivated by mastery goals, although her emotional experience may not be optimal, she potentially will regulate such emotional experience and redefine cognitive goals to pursue. Mastery goals again point to desirable attributes for student engagement with academic activity.

Kathy

Kathy's engagement with the fence problem

During whole class instruction regarding the fence problem, Kathy had an active role in our discussions. Her contribution to the discussion was largely to pose questions focused on understanding the different aspects of the problem. For example, after we had worked with the rectangle aspect of the problem and began to transition to think about regular polygons, we asked how we would determine the area for polygons we did not already have a formula for. It was this question which led the class to consider using the measure menu on GSP in order to simplify the process to find the area of a variety of regular polygons.

When the students began using GSP to engage with the fence problem, Kathy settled into her chair behind Wendy and Faith. She observed Wendy's efforts and on her own created a file represented in figure 15, which has been scaled to fit the page. She used a method similar to Wendy's to construct the regular 30-gon and then measured the perimeter of the polygon. She pulled the circle to construct a regular polygon with a perimeter approximately equal to one hundred. Her choice to rotate a point on the circle twelve degrees about the center appeared to be original since no other student near her chose this degree measure.

Kathy also endeavored to assist Walt several times when he reached an impasse. He did not receive these supportive efforts from Kathy in such a way to improve his efforts with GSP. However, Kathy's efforts to support her peers as they engaged in activity are indicative of the mastery goals I ascribe to her.

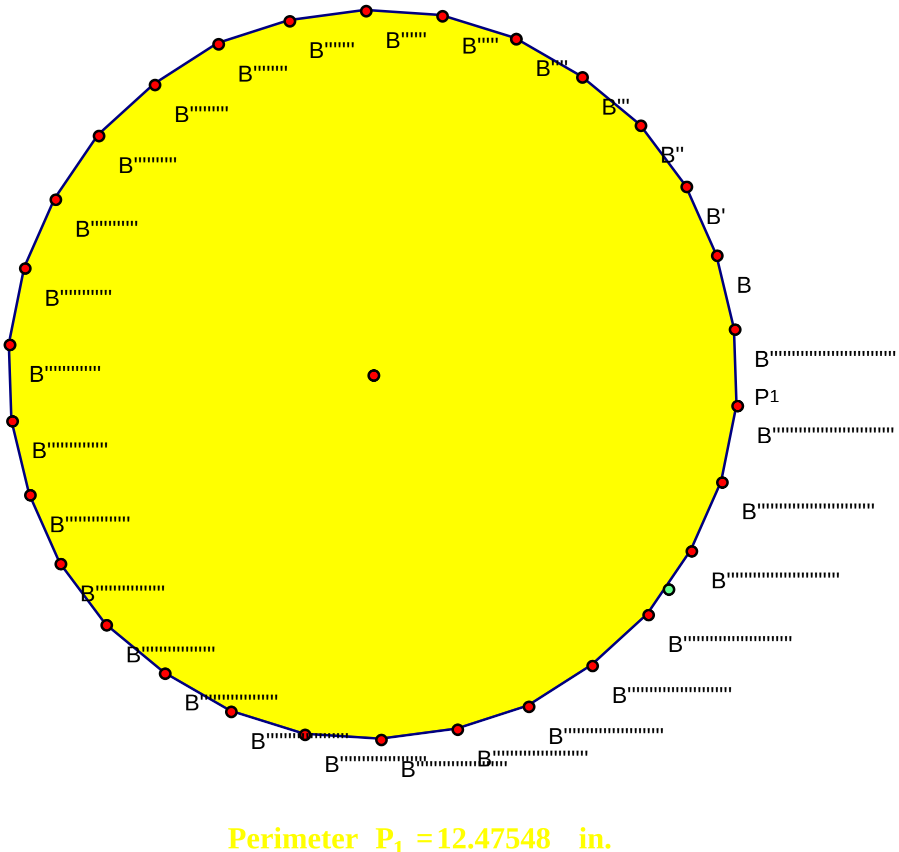

Figure 15

Use of technology tools

Kathy's use of technology tools was limited given her willingness to allow Wendy to be the primary user of the computer. When she did use the tools, she was able to mimic Wendy's or my demonstrations of constructing a regular polygon. Of note is Kathy's choice to hide the circle used to construct her regular polygon. In the file she saved there is a clear separation between the point she used to enlarge her constructed polygon and the vertices and sides of the polygon itself. This choice exemplified a difference in how Kathy chose to use the tool and how her peers used GSP.

Kathy's affective experience during the fence problem

Although it is difficult to make a case for my assertion, I claim Kathy's affective experience was productive for her engagement with the fence problem. She appeared to enjoy observing her peers work with GSP and Excel and with regard to GSP, Kathy was able to carry out the exemplified procedures to construct a regular polygon. Also, since she and Wendy worked cooperatively I contend Kathy enjoyed a pleasant experience thinking about mathematics.

Given the mastery goal orientation she was largely motivated by, Kathy had a desire to understand the content we were studying. Having the opportunity to engage with mathematical activity on her own terms, Kathy was able to experience productive affect. Also, since she had the opportunity to approach goals of her choice, Kathy was also able to engage in her goals to interact socially with her friend and experience no negative consequences for these actions. Thus her emotional experience provided productive affective experience enabling Kathy to remain engaged with the fence problem for an extended period of time.

Kathy's engagement with guess my rule

Again while the class worked with guess my rule Kathy patiently observed her classmates actions with technology tools. Because she engaged with each of the three students, who were primarily operating the machines and discussed some the mathematics they were doing, I believed she was not sitting idly, but rather was attempting to understand the mathematics the others were exploring. She attempted to assist Walt to make the computer do what he wanted. However, the majority of the time she appeared to be actively observing. Observing Kathy and developing my assumptions about her level of engagement led me to wonder what can she do once given the opportunity to use the software on her own?

As I described earlier, Kathy worked cooperatively with Wendy as they started engaging with guess my rule. Having developed the files represented by figures 4 and 5 cooperatively, she then proceeded to create a file independently on March 18. The file Kathy created, represented by images in figures 16 and 16.1, showed she was thinking about typing rules and using these to ‘fill down’ a column of a t-chart. In each column she used two operations to generate the number. For the independent values she chose to add 6 to the value in the cell above and then to subtract 3. Here Kathy’s freedom to choose what she wants to enter into the formula bar affords her the chance to experience equivalent expressions. She may recognize the connection between what she entered, + 6 – 3 and the software’s output where each successive number is 3 larger than the previous one. Hence Kathy had the opportunity to develop her own understanding. Further granted she realized adding would produce larger successive values, she is afforded the chance to see that the magnitude of negative numbers decrease as the values get larger, an oft misunderstood phenomena.

x	y
-7	-35
-9	-45
-11	-55
-13	-65
-15	-75
-17	-85
-19	-95
-21	-105
-23	-115
-25	-125
-27	-135
-29	-145
-31	-155
-33	-165

Figure 16

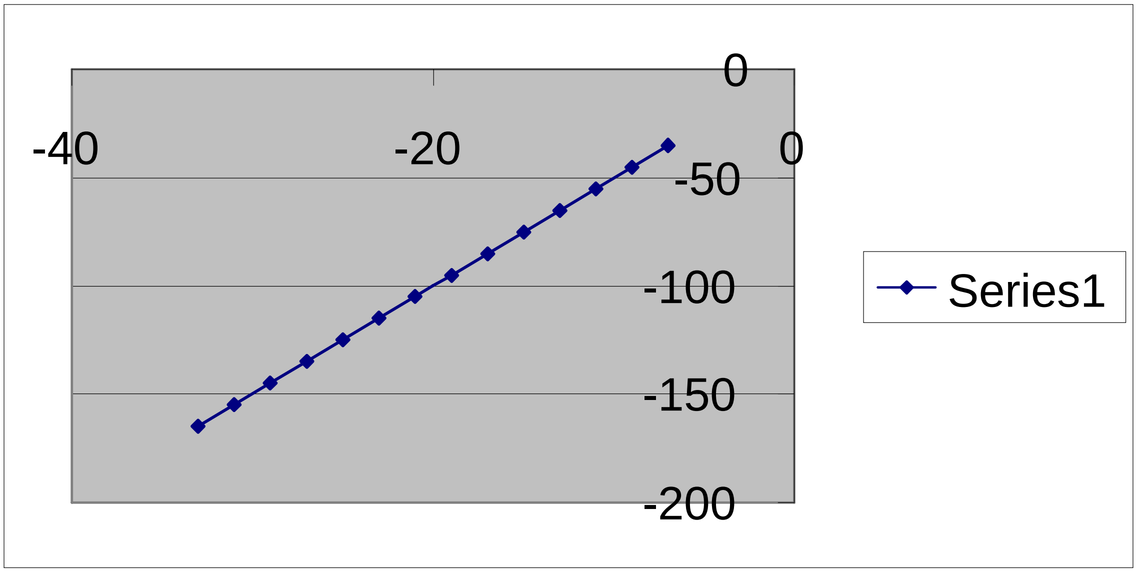

Figure 16.1

Kathy also used two operations to generate the dependent values. She chose to multiply each respective independent value by 7 and then to divide this product by 2. Here, however, the software's limitations removed some potential patterns that Kathy would have had a chance to think about. The aspect of the software that proved limiting here was the space allowed to display the dependent values. Because I had asked the students to enlarge the size of their numbers so the objects on the computer screen would be more visible to the camera, Excel only displayed each value to three digits. Every value associated with an odd independent value could not have been an integer since 2 was a divisor in the rule that Kathy used. This fact is not seen in figure 17 due to the nature of the pasting; however, on Excel the dependent column did not show any decimal representations, save –94.5. In order to fit a value into a cell, Excel rounded all the non-integral solutions to the nearest integer.

This lacking representation of the dependent values was not problematic for Kathy. She seemed to not connect the relationships between 7/2 and the differences in her dependent values divided by the difference of independent values. I suspect, somewhat optimistically, that had the differences between successive values differed more dramatically than in Kathy's t-chart she might have experienced disequilibrium had she noticed the independents change by the same amount, should mean the dependents will as well. Thus this limitation of the software did not trouble Kathy but had the differences been more drastic she could have recognized that there was a problem with the representation.

x	y=7x/2
-63	-220.5
-60	-210
-57	-199.5
-54	-189
-51	-178.5
-48	-168
-45	-157.5
-42	-147
-39	-136.5
-36	-126
-33	-115.5
-30	-105
-27	-94.5
-24	-84
-21	-73.5

Figure 17

Use of technology tools

The files Kathy created are evidence addressing my question of what will she be able to do once using the technology tool herself after having spent a large portion of time observing. She was able to operate in this fashion because she did engage in discussions with each student about what they were doing, primarily with respect to the mathematics of the others efforts. Kathy reported using computers at home, but not to having practiced on Excel. Thus I am lead to conclude that her ability to operate efficiently was due in part to observing others use the software, but only to the extent that she understood what they were doing. Kathy's questioning and effort to connect what she sees with what she already knows are the essential dispositions allowing her to operate as she did. This fact offers some support for the notion that a classroom need not have enough computers so each student can use one at any given time, but it is critical the students not operating the software be actively trying to make sense of what others are doing.

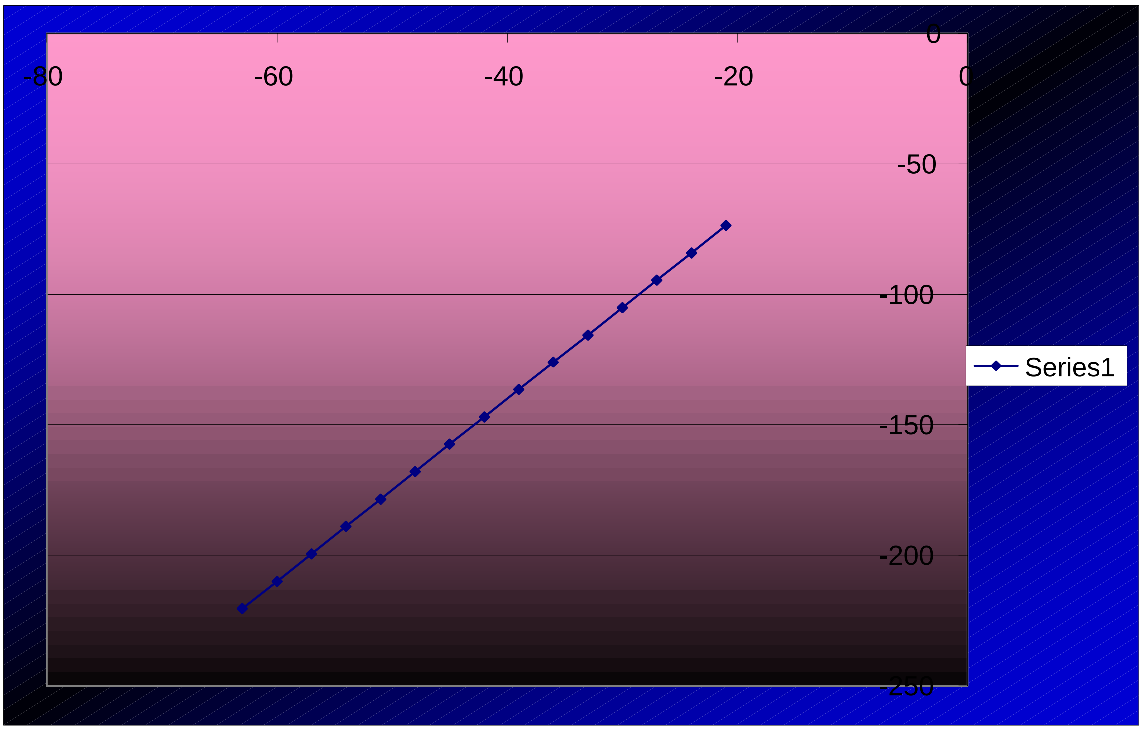

Figure 17.1

Kathy's use of technology tools was necessarily limited given her willingness to observe her classmates. Her choice to observe was connected to her stated distaste for technology in general. She commented in one of our recorded conversations she did not like technology and didn't understand why so many people were so excited by technology. Wendy was present at this time and looked at Kathy with an expression implying 'what are you talking about, girl.' Kathy saw this look Wendy gave her and simply said, "I don't think technology is all that." Kathy did however use the computers towards several of her goals.

The cooperative nature of Wendy and Kathy's early work with guess my rule supported Kathy's later efforts with Excel. Observing my demonstrations, Wendy's efforts and Faith's work, Kathy developed a solid sense of the procedures to use Excel to produce a t-chart by filling down. She also was able to produce graphs of her values and alter the appearance of these graphs to suit her preferences. Further she could save files into locations of her choosing. Kathy was the only participant to use different computers and she had created personal folders on each into which she saved her files. Although some of her efforts with the tools may have been original and learned on her own, she did observe another user operating in the ways she used technology tools. One hindrance to Kathy's efforts with Excel was her lack of conceptual understanding of what the tool actually did when a user inputted a formula into a cell or filled a formula down a column. Early in our work with the fence problem while Kathy was using Excel she turned to ask me for a calculator. She wanted to be sure she entered the dimensions of her rectangles correctly. I tried to explain Excel was a calculator and she only needed to tell it what to calculate. This explanation was not effective for her understanding of the software. During work with guess my rule Kathy again requested a calculator. Only Kathy and Walt were at the computers as I walked by, she asked me if she could use a calculator. I offhandedly told her she was using a calculator. Her puzzled look told me she did not conceptually understand how Excel operated. Thus, Kathy was most likely to only use Excel in ways she observed others using the software.

Play while engaged with guess my rule

Kathy played while engaged with guess my rule in several different ways. She used the software to produce graphs from her t-charts and then played with the aesthetics of the representation to produce an image which was pleasing to her. She also played with Wendy during Wendy's activity to produce rules for Kathy to guess. This playful engagement was not mathematical, but rather Kathy was playing with the social interaction between she and Wendy.

Analysis of her saved files (Figures 16 & 17) did represent a progression of activity toward mathematical play. In figure 16 she generated the independent values by adding negative two to each successive value. She then chose to multiply each independent value by five to generate the dependent values. Her work represented in figure 17 shows her playing with the mathematics used to produce the t-chart. To form the independent column of values, Kathy chose to add six and then subtract three from each successive value. She then chose to include two operations to produce the dependent values, namely multiply by seven and divide by two. This progression was indicative of Kathy's actions to not only produce a rule which was more complicated to guess, but also to stretch beyond the mathematics which was easier for her to comprehend. This activity took on a playful orientation since Kathy chose numbers she wanted to think about.

Kathy's affective experience during guess my rule

Kathy's patience dominated her affective experience. On several occasions the video evidence depicted Kathy attending closely to Wendy and Faith's work with technology tools. However, at any instant when one or the other of the girls would vacate their seats, Kathy would slide into their chair, after being certain they were 'finished', and then proceed to use Excel in a manner of her choosing. Often this activity was related to guess my rule, but she was observed playing with Excel several times to learn what else she could make the software do. These actions were primarily geared towards altering the aesthetics of her files.

Kathy's patience was prominent given she valued observing her peers and attempting to understand their actions. Never did she complain to me about not getting a fair share of time at the computer. However, she also did not appear to mentally checkout while her peers were engaged in activity. She remained engaged in large group discussions and happily moved to the computers when it was appropriate to do so. Thus, I contend her affective experience was productive for her engagement in mathematical activity.

CHAPTER 6

Conclusions, Implications, Limitations, and Plans for Further Study

Conclusions

I conjectured technology tools could provoke playful engagement with mathematical activity. Students exhibited such activity on several occasions as typified in the previous chapter. Engaging with mathematical activity playfully also was hindered at other times. The tendency to play was tightly connected to a student's affective experience. When a student experienced success and felt good about their efforts or their products, in general, they were motivated to continue to engage with the tool and potentially with mathematics. However, occasions with the computers certainly provoked unproductive affective experiences as well. These were largely typified by an inability to make the tool work in an attempt to satisfy a chosen goal.

The broad conclusions offered above are further refined and addressed by returning to my research questions. My first research question, how does the opportunity to use technology tools while engaging in mathematical problem solving provoke a middle grades student's mathematical play, has a wide range of responses. First, the fact technology tools were incorporated allowed students a wider range of activity. The opportunity to use tools promoting a wider range of activity allowed for what I have termed technology play and aesthetic play to occur. Thus the incorporation of the tools provoked forms of playful activity in addition to mathematical play while students were engaged in problem solving.

A student's play was also related to their competence with the tool. In some cases students with little understanding of how the tool worked or what it could do engaged in technology play and a broader range of activity with the software as they worked to understand how the tool worked and what they could do with it. There was also evidence students, who were not particularly competent using the technology tools, discontinued engagement with the software when they could not determine how to use the tool to approach their goals. Here the structure of the microworld provided by the software was a contributing factor to students' activity with the tool. For instance Walt was able to use GSP for more productive mathematical activity than he was able to use Excel. This fact is largely due to his preferred method of engagement with technology and the fact GSP's structure afforded him the opportunity to use the software as he wished. Wendy and Kathy also engaged more playfully with GSP than Excel. Their engagement was supported by the structure of the microworld within GSP and also by their goals for activity. A deeper understanding of the role of the specific software corresponds with the call to examine how particular technology tools influence student activity (Kaput, 1992).

As students used the tools more regularly and gained more competence with the tools their play became more sophisticated. Since they could use the tool more effectively, they were able to enact a wider range of actions and provided themselves the opportunity to play further. Their increasing competence with the tool facilitated strong connections between actions termed technology play and those representative of mathematical play. This blending of playful activity made distinguishing where one form stopped and another started more difficult. For example, Faith and Wendy were more prolific than other students in the class due to their competence and the time they had to use the tool. Since Faith had access to her own computer and Wendy dominated the operation of the computer when she and Kathy engaged with the problems described, Faith and Wendy were able to spend a significant amount of time learning what they could do with the software. Their competence with the software supported their efforts to play by removing the need to focus on how to carry out an action and allowed the girls the opportunity to find out what could be done with the tool via playful engagement. As they played with the tool and engaged in mathematical activity, their activity was interpreted to transition between technology play, aesthetic play and mathematical play. As they were able to use the tools more efficiently and yet still worked to learn more about the software the boundaries between their playful activities blurred.

On the other hand, Walt and Kathy's experience, which produced fewer mathematical products, was directly related to their time with and understanding of the technology tools. Both students spent less time engaged with the software than their peers. Additionally, Walt and Kathy did not exhibit competence with the software akin to Wendy or Faith. Having less time to work and not developing significant abilities with the tool often go hand and hand. Unfortunately these factors limited the opportunities for Walt and Kathy to engage playfully. Interestingly, both Kathy and Walt stated their preference for spending time with one problem and not rushing ahead to another problem as they had in previous mathematics courses. Independently, they explained by spending more time with a problem they felt they were able to gain a deeper understanding of the mathematics we were studying. Had they also been able to devote significant, productive time with the technology tools, Walt and Kathy could have improved their tool use and potentially gained experience playing with the tools and with mathematics.

I focused on each student's engagement during activity and therefore a student's goal orientation further addressed how technology tools provoked play. Since human activity is goal directed, as described in chapter two, when a student is motivated by goals leading to actions of the student's own volition as opposed to actions in accordance with perceived teacher mandates, ones play, in general, as well as with technology tools while problem solving, differs. For instance, Wendy played within the structure with which she thought she was supposed to engage.

Her performance approach goals provided motivation for continued engagement when she experienced perturbation, but her activity rarely moved beyond the boundaries of the posed problem. Thus, if she was to engage playfully the posed problem had to allow opportunity for such activity. On the other hand, Faith extended the structure of problems I posed and engaged in activity with a broader range of potential. Her mastery goals opened a wider path for her activity. Since she was motivated to learn more mathematics, she was able to engage with aspects of mathematics Wendy did not explore. Walt's goals hindered his play except in the case of using GSP. His performance avoidance goals did not support further engagement when he experienced perturbation. Because he was motivated to avoid difficult situations and equilibrated by focusing on goals that were largely social, his opportunities to engage playfully were limited. Kathy, motivated by her mastery goals, engaged in mathematical activity in order to learn more mathematics. The limited amount of time she had to use technology tools directly influenced limitations of playful activity. A mastery goal orientation did support a student's ability to redefine goals during activity. This redirection of engagement was supportive of further activity in general and playful activity in particular. These characterizations of goal orientation and the student's associated activity are consistent with the descriptions offered in literature informing this study (Eccles & Wigfield, 2002).

The second research question examined the impact on student's affective experience if mathematical play occurs while a student is using a technology tool. Such play proved to influence a student's affective experience in a productive fashion. This conclusion is consistent with the literature supporting productive outcomes and positive affect (Isen, 2000) and the consideration of what students were doing as they played. They were acting autonomously and trying to find out what they could do with technology tools, as problem solvers, and in mathematics class. Students were able to act in the moment and progress at their chosen pace. They were enjoying themselves and learning about ideas they were willing to investigate on their own terms. So it is not so surprising their affective experience was productive when they engaged in activity playfully. These occasions to play in mathematics classes eased the transition students experienced as they moved from a primarily teacher-directed classroom into one requiring they take more responsibility for the evolution of the curricula of the course.

Another conclusion relevant to the second question is the characterization of affective experience I have used and its effectiveness in interpreting student affective experience while engaged with activity. Scholars have stated measures to assess student affect have often not been administered while students were engaged in activity (Boekaerts, 2002). Here, by gathering data while students were engaged in activity this concern is addressed. Further the characterization of affective experience as the transactions between a student's emotional experience, motives and cognition provided a way to address variations in a student's affective experience. Since a student's goals have been linked to the transactions between motives and cognition (Schutz, 1994) and emotions, motivation and cognition have been described as the key components of human activity (Meyer & Turner, 2002), the conclusion presented linking goal orientation to play has relevance for affective experience as well. With respect to affective experience when a student was able to redefine goals in order to cope with an experienced perturbation, affective experience remained productive. However when a student did not redefine goals, affective experience suffered and engagement became less productive. Thus, a student's goals mediated the transactions between emotional experience, motives, and cognition while engaged with activity.

These conclusions lead to the finding that when students play during school mathematics their affective experience improves. Further, this improved affective experience and opportunities to play allowed students to engage in mathematical activity more productively and to pursue original goals for their problem solving efforts. The incorporation of technology tools in a problem-centered mathematics class allowed students a greater range of activity that could be approached playfully. Therefore incorporating technology tools in student's school mathematics experiences and using pedagogy aimed to promote student play, be it aesthetic, technology, or mathematical play, further benefited students' affective experience, their engagement in original mathematical activity, and their learning of significant mathematics.

Implications

Implications for this study include the mathematics students learned during this course and while engaged in problem solving playfully. As classes of seventh graders go, my students were not the strongest mathematically. They had received mathematics instruction from teachers who knew the content and presented it in a teacher-directed fashion. These teachers commonly voiced their concerns to me about teaching mathematics and about their students learning. They felt many of the students did not seem to be able to remember facts from one week to the next. This comment was aimed at the student body in general and not just relative to the students in my class. Such generalized concerns of teachers were valid since district-wide one mathematics teacher per grade level taught every student for grades 4 – 8 until the year of this study. My group was below average when compared to their peers in the seventh grade. Even though the number of students fluctuated during the year, of the eighteen students in the class for the entire year, more than a quarter of them were labeled and received services from the system's special education specialists, representing a greater percentage than in the seventh grade as a whole.

Additionally the strongest mathematics students were in a homogenously grouped section taught by Henry. Therefore, this study's implications for student learning hold weight for a large segment of students rather than being applicable only to a minority. Because the transitions in mathematical activity I ascribe to my students have been suggested to not be important for or impossible to enact with weaker students this empirical evidence of their growth given the opportunity to play becomes more relevant for efforts to reform school mathematics and address issues of equity.

Since engaging in activity playfully has been shown to improve affective experience and positive affect is linked to further learning, it is natural to ask what did the students learn during the year of the study? This question is important to the study's implications and lends itself to a variety of potential answers. With respect to state objectives for mathematics courses in seventh grade as measured by students' scores on the state's end of year test, their experience during the year at worst did no harm. In fact, the testing administrator for the middle school reported to me how pleased she was with my students' performance. Further, my students, without prompting, reported to me they felt competent with their efforts on the test. Contrasting with their peers in other courses, my students explained the test seemed easy and they felt they had been well prepared. Thus by posing problems, encouraging students to persist and support their assertions with reasoning, the students learned significant enough mathematics to support their efforts on the state's test.

With respect to student learning, a more important implication of this study is the transition students made in what they viewed as acceptable mathematical activity. Relying on students' final project presentations as evidence, a noticeable change had occurred. Students demonstrated an expectation peers support the conclusions offered during presentations and actually do significant mathematics related to their topic. In questions posed to the presenters, students explained they wanted to know why the presenters had not investigated ‘seemingly obvious’ mathematical concepts related to their topic. Also, students asked questions about specific aspects of their peers’ graphed representations of collected data and about computations used to arrive at offered solutions. This questioning was a marked transition from the beginning of the year when some students wondered silently and others aloud why I kept at their peers for reasoning to support a proposed solution to a problem. Their questioning is evidence the students had furthered their beliefs about what school mathematics could be. I contend the opportunity to engage with technology tools playfully aided this transition since students were able to engage with the tools to further their mathematical thinking. This alteration of belief about mathematical activity signified critical learning about the nature of mathematics.

Another set of implications for this study relate to incorporating technology tools into school mathematics. For example, what sorts of computer arrangements work in a classroom? Kathy learned about using the software while she observed more proficient users. Thus, not having a computer to operate independently at any given time was not completely detrimental for Kathy. However, her conceptual understanding of how the computer functioned was limited because she observed and then acted primarily as Wendy and Faith had, much like the mathematics student who copies a more knowledgeable other’s procedure and then mimics the actions for another example. Kathy was certainly anxious to use the computer, although she preferred to let Wendy use the computer and rarely demanded a turn for herself. Although not operating the computer was beneficial for Kathy at times, other students took the time away from the computers as somewhat of a break time and did not observe others actions with the attention Kathy gave her peers’ actions. Thus, if every student does not have a computer a teacher must work to develop a classroom environment where students value observing their classmates actions and ideally interacting cooperatively. However, observation and secondhand interaction is not sufficient. The students must have significant experiences with the technology tools and thus need to feel empowered to insist they receive opportunities to operate the computer.

Another implication for the incorporation of technology tools in school mathematics is related to the use of a demonstration computer to run mathematical software and a projector to display the actions carried out and the resulting consequences of these actions. The incorporation of a computer/projector as a demonstration tool effectively captured the attention of a greater portion of the class for a longer period of time than my board presentations. Of course, the element of the frequency with which I used the computer/projector was unique to their prior school experience. Regardless being able to see the computer operate and observe the visual effects produced, drew the attention of most students for prolonged periods of time. These occasions of demonstration for the whole class also provoked a variety of ‘what if’ questions. Students were free to interrupt me and pose questions regarding my actions and what would happen if I performed a particular action. Sometimes I carried out this action so their curiosity would be fulfilled. Often I encouraged them to try such an action when they moved to work with their computer. Therefore using the computer/projector as a demonstration tool could provoke a student’s conjectures and presented an avenue for engagement for this student as well as others who found the idea interesting.

A further implication of this study related to technology use is methodological in nature. In order to study a student’s play it is critical to capture their actions and work products. Analyzing only the final product of a student’s activity may lead to a researcher to surmise play occurred in order to produce the artifact. However, analyzing a student’s engagement with activity in its totality allows a researcher to more clearly interpret the student's activity. Such analysis can lead to characterizing the subtle differences existing as a student engages in activity. The video record of the student's actions was clearly an important aspect of this study, but I contend the use of technology tools themselves hold implications for further study of student activity. Because the tool can record a student's actions and keep a record of when specific objects were constructed, incorporating technology tools into school mathematics can enable improved research of student activity.

Building from the implication technology tools can be used to further study student activity and better characterize the subtle nuances of activity as they occur leads to implications of this study for how play and goals transact. First, play is in the eye of the beholder. The stronger the model of another's understanding the beholder uses the more clearly play may be interpreted. In particular, understanding how a student defines goals for activity allows an observer to better understand when a student is playing. This understanding is important given the implication of this study binding play and goal theory. Play was shown to influence continued student engagement with problem solving. Therefore increased student motivation can be linked to opportunities to play. Since being motivated to engage in problem solving is key to mathematical activity there exists a connection to learning of mathematics which is promoted by this motivation derived from opportunities to play. Now given a student's goals provide for the transactions between motivations and cognition, play may be linked to student goals. More precisely engaging playfully allows student's the opportunity to identify their own goals for their activity. Thus, as more activities in school mathematics are engaged in playfully this study's findings imply student's can define productive directions for their mathematics learning.

Directly related to the production of a student's goals through playful activity are a set of implications, related to a teacher's practice. First, there will necessarily be a tension between the student's goals during activity, the teacher's goals for the student's activity, and the student's perceptions of the teacher's goals. Thus, I claim it is necessary for a teacher to set aside certain preconceived notions about acceptable actions in school mathematics if productive opportunities to play are to be provided for students. At times I found myself reproving students for not engaging as I felt they should. In several of these cases I later decided I had responded too hastily and likely closed down the student's opportunity to engage playfully.

Also, a teacher attempting to incorporate technology tools and planning to provide student-centered experiences constituting a significant transition for their engagement needs to be able to rationalize the risks taken. Everyone who has used technology realizes there are times the tools do not operate as we planned. Thus one risk is inherent in just counting on the machines themselves. Further, a teacher then must attempt to address these glitches in the moment and potentially lose time with students. Second, when a student is confronted with experiences differing from their expectations, there is a possibility they will balk at the changes. Hence a teacher must accept the risk students will disengage and be prepared to present alternative options for students' activities.

Incorporating opportunities for playful engagement in a student-centered classroom also places a burden on a teacher's pedagogical content knowledge. A teacher must craft appropriate problems, listen to students, and address student questions as they arise. If students are engaging playfully, then a teacher must make sense of the student's goal and the potential for mathematical activity found in their actions. This process takes time and must be started anew as the teacher moves to address another student. Thus there seems to be no prescription for a set of practices necessarily fostering play. My own playful nature likely facilitated some students willingness to play, but a less playful teacher could also provide opportunities for student's to engage playfully.

Although these implications for teacher practice may prove daunting, the payoff can be worth the effort. If one accepts the role of a teacher is to actively build models of a student's understanding, then students engaging in mathematical activity playfully can be strongly supportive of such pedagogical practice. When students play, a teacher has the opportunity to more clearly understand their motives for engagement and the interest a topic may hold for the student as they engage in activity they deem pleasant. When engaged in the activity the teacher has presented, the student's actions are informative to the teacher's model building along a narrow spectrum of the model because these actions are necessarily within a narrower field of activity. However, when the student plays more ground in the field may be covered. Therefore, a teacher has the opportunity to develop a broader model of the student's understanding. Thus, an important implication of this study is providing opportunities for students to engage playfully allows a more complete model of the student's understanding to be developed. For example, I understand more fully how Faith, Kathy, Walt, and Wendy are motivated and what aspects of particular activity they found interesting or boring, pleasant or bothersome. This information was beneficial for my efforts to provide further learning opportunities for the students.

A further implication of this study is providing opportunities for playful engagement with mathematics is useful as a method to introduce big ideas. A faction of mathematics educators who believe students should not engage in problem solving until they have acquired the predetermined requisite skills may not accept engaging playfully with a topic as an effective introduction. However, the model of a student's understanding I was able to build given their playful engagement was more informative for my assessment of a student's attained understanding and could be used to focus further mathematical activity more effectively.

Limitations

A limitation of the present work is only I analyzed the data. Admittedly, I have a greater understanding of the student's experience with school mathematics than others, but another perspective regarding student engagement, playful activity, and affective experience would strengthen this study. For example, if another researcher's analysis of the data were to be offered the nature of a student's activity while technology play and mathematical play interacted could be further interpreted. In short, multiple perspectives would likely assist in further explicating the relations between the constructs studied.

Also, attempting to operate as a teacher/researcher while conducting this study produced a variety of gaps in my pedagogical practice and research efforts. For example, I chose to focus my efforts on aspects of my experience other than regular journaling. Thus my field notes are sparse and minimalist. Also, I collected few written artifacts from students on a periodic basis. Instead I chose to collect their written work at the end of the year. I asked students to let me keep their years worth of notes and problem-solving attempts. I received several sets that were well organized and regularly dated. I looked across these and gained student perspective on the activities of the year as well as used them to define exact time frames for our whole group work. However, more thorough field notes and collecting artifacts with greater regularity would likely strengthen the study.

A perceived limitation of this study relates to the number of participants. By incorporating a larger sample and employing quantitative instrumentation researchers could assess the goal orientation of a large number of students. Also, by including tools to allow students to self-report on qualities of their affective experience, another lens may be applied to the emotional experience, motives and cognition of the students. Further research questions could then be addressed which aimed at understanding the relationships between a student's goal orientation, engagement with mathematical activity and/or technology tools and affective experience during such engagement.

Also, increasing the sample size would open opportunities for investigation of students who are often viewed as non-participatory. I am keenly interested in these students' engagement and associated affective experience. My fears of not attaining understandable data, however, led me to not choose participants for this study from such a set of students. Thus the conclusions of this study are limited in the sense I chose to exclude students I identified as largely non-participatory.

Further Study

Given my chosen methods of analysis I attended more globally to a student's problem solving activity. An area for further study could investigate student's problem solving activities with technology tools with greater attention to Polya's phases of problem solving. In attempting to describe mathematical play theoretically I proffered examples of potentially playful occasions related to these phases. If student's problem solving activity were analyzed at the level of these phases, mathematical play as a construct and ways to support student play may become better defined. I am led to initially conjecture mathematical play would prove a mediator as students returned to earlier phases when experiencing perturbation. Also, those students who are strongly motivated to engage in mathematical play would gain the opportunity to experience the fourth phase of problem solving in school mathematics.

An area for further study related to the conclusions offered involves further investigation of the role of technology tools in school mathematics. One focus of such a study would be on the opportunities for student activity provided by the tool in particular. The ways students used GSP and Excel were inherently different and promoted different experiences for students. A stronger understanding of how these tools promote mathematical play would not only hold implications for teacher practice to incorporate technology tools, but it would also support further explication of play. Another focus of a study where students use technology tools while problem solving would investigate the variations of playful activity identified, technology play and aesthetic play, and how this activity fosters mathematical play. This study may also attend to the relationships between technology play and mathematical play as a student becomes a more competent user of the technology tool.

I have offered several directions for further study with regard to problem solving, mathematical play, and the incorporation of technology tools in school mathematics. A different line of inquiry to consider relates more directly to socio-historic and psychological aspects of school mathematics. One extension could address questions related to the relationships between student and teacher during school mathematics. For example, if mathematical caring relations between student and teacher are important for school mathematics experience, then analysis of data reflecting how a student perceived a teacher, who was identified as having perturbing intentions, would be informative for the field. The relationship between teacher and student is a fundamental concern for my teaching and potentially for other’s practice as well. Further study in a related vein could investigate the social interactions between students as they engaged in mathematical play with technology tools. Although some conclusions might be drawn from the role Kathy chose to take during activity, there is a much wider range of social interaction to explicate to more fully understand how mathematical play with technology tools more fully influences student learning and affective experience.

With regard to further study of constructs more commonly studied by educational psychologists, one avenue to investigate is surely the identification of and how a particular discrete emotion influences mathematical play in particular and student affective experience in school mathematics in general. Since the analysis of this study relied on dimensional emotions theory, explicating the influence of a particular emotion would further our understanding of student experience in school mathematics. Another direction for investigation would attempt to explicate the role of a student's self-regulation when experiencing perturbation and how self-regulation connects with a student's play. Faith's efforts to regulate her experience allowed her to remain engaged in mathematical activity. Understanding how Faith's and other student's self-regulation influenced further activity and led to playful activity would also be a productive line for additional inquiry.

Finally, and of great personal interest, is an extension of the present study to investigate the affective experience of adult learners as they engage in original mathematical activity with technology tools. Specifically I would prefer participants be prospective/practicing teachers. With similar analytic techniques researchers could characterize the adults' playful engagement. This study could then be extended by investigating how such experiences influence teachers' classroom practices and the value they ascribe to providing opportunities for students to engage in original mathematical activity playfully.

Spending time with typical middle grades students one becomes aware these people are playful with regard to a variety of activities. I strove to learn if play could be enacted in a problem-based mathematics class with average students, who had experienced traditional mathematics courses previously. I conjectured play could mediate such a transition for students and I believed play could promote experiences for students which allowed for challenging mathematical thinking as well as enjoyable experiences during the course. This study offered evidence middle grades students' playful activity can be mathematical. The students' playful activity became broader when technology tools were integrated. These opportunities to use technology tools to play while engaged in problem solving proved beneficial for student's affective experience. The students were motivated to engage in problem solving for longer periods of time than when they were not playing and they learned significant mathematics. Of course, the learning of mathematics is a critical element for students' experiences, but the fact many students had pleasant experiences during the course allowed this learning to occur. Thus, given the positive outcomes of this study, mathematics educators should strive to provide opportunities for students to play in school mathematics.

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APPENDIX 1

Communicating research plans with caregivers

1/10/05

To the parents of my mathematics students,

First, I want to wish everyone a happy and prosperous new year. After a very pleasant holiday break, I look forward to more opportunities to support your children as they work to learn more about math. You might recall that I have previously sent you all a letter communicating my future research efforts in your child's math class. Well the time has arrived when this project will begin. I will continue to pose problems for the students in my class to help them learn more as well as new math. They will continue to have the opportunity to use computer software and the Internet on many of these problems and in their efforts to learn new concepts. The added component is that there will now be one to three digital video cameras in the classroom at a given time. The cameras will capture the actions of various students who have been chosen as the central participants of the study. Information about the expectations of the central participants will be sent to their parents when I request the consent of the parents to allow their child to participate in my study in this role. For all parents of children that are not chosen as central participants, I want to make it very clear that your child will not receive less attention and support than in the past. It is very important to me and I have taken great care in planning this study to take every step possible to continue to treat each student equitably. If you have any concerns that you would like to discuss with me please do not hesitant to get in touch with me. I can be reached by phone at school, 770 464 1932 ext. 2115, between 11:30 and 1:00 or by email at jklerlein@scboe.org. Thanks for your time and here's to looking forward to a successful semester of learning about math.

Sincerely,

Jacob T. Klerlein

APPENDIX 2

Communicating research plans with students

OK everyone; we need to have a talk, now. Remember I told you that one reason I came to teach here was to have a place to conduct my dissertation research so that I could finish my doctoral degree. My plan is to conduct a research study with students where they use technology to solve math problems. I will let everyone use computers to work on these problems. To go one step further I will also videotape some of you while you work. Those of you that I videotape will also talk with me during your life leadership class. We will talk about your feelings while you were using the computers to solve the math problems and how your feelings affected your motivation and your thinking. I have some ideas about which of you I want to choose for this role, but before I can make the final choices I have to get your permission and also the permission of your parents to include you in my research in this fashion. If you choose not to participate, I will not be angry with you and you will not lose any privileges or get a lowered grade in this class. I want you to all understand that my choice does not have anything to do with how good you are at math. Also, I want you to trust that even if I do not choose you to be videotaped while you work, I will still do all that I can to help you while you try to solve problems and learn more about math. If you have any questions, let’s talk about them now. Who would like to go first?

APPENDIX 3

Parental permission form

I agree to allow my child, ______________________, to take part in a research study titled, "Student affect during mathematical problem solving", which is being conducted by Mr. Jacob Klerlein, from the Mathematics Education Department at the University of Georgia, (UGA) (706-338-9639) under the direction of Dr. Jim Wilson of the Mathematics Education Department at UGA (706-542-4194). I do not have to allow my child to be in this study if I do not want to. My child can stop taking part at any time without giving any reason, and without penalty. I can ask to have the information related to my child returned to me, removed from the research records, or destroyed.

- The reason for the study is to find out what role technology plays in your child's emotions and motivation towards mathematical problem solving.

- My child's regular classroom activities, which involve solving math problems that incorporate technology, will continue. Additionally, my child will be observed, notes will be made regarding their efforts, and their work will be video-recorded for approximately ten hours. My child will also participate in audio-recorded interviews during their life leadership session. My child's actions on three to five problems will be the focus of the study, and no more than three, 20 to 40 minute interviews will be conducted for each problem. If I do not want my child to take part in the study then s/he will be allowed to function in class as usual.

- Children chosen to be video-recorded and interviewed may learn about how their emotions play a role in their thinking and motivation. By gaining this knowledge, a child may learn how to use these feelings to work more effectively on challenging tasks. The researcher also hopes to learn something that may help other children have better experiences with mathematics in the future.

- The research is not expected to cause any harm or discomfort. My child can quit at any time. My child's grade will not be affected if my child decides to stop taking part.

- Any information collected about my child will be held confidential unless otherwise required by law. My child's identity will be coded, and all data will be kept in a secured location. All data will be erased on or before May 14, 2011.

- The researcher will answer any questions about the research, now or during the course of the project, and can be reached by telephone at: 706 338 9639. I may also contact the professor supervising the research, Dr. Jim Wilson, Mathematics Education Department, The University of Georgia at 706 542-4194.

- I understand the study procedures described above. My questions have been answered to my satisfaction, and I agree to allow my child to take part in this study. I have been given a copy of this form to keep.

Jacob T. Klerlein ________________________ __________

Name of Researcher Signature Date

Telephone: 706 542 4537

Email: jklerlei@coe.uga.edu

__________________________ ________________________ __________

Name of Parent or Guardian Signature Date

Additional questions or problems regarding your child's rights as a research participant should be addressed to Chris A. Joseph, Ph.D. Human Subjects Office, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706) 542-3199; E-Mail Address IRB@uga.edu

APPENDIX 4

Student Assent Form

Dear Participant,

You are invited to participate in my research project titled, "Student affect during mathematical problem solving." Through this project I am learning about ways that technology can be used while boys and girls are solving mathematical problems. I will be working to understand how using technological tools influences your feelings, motivation and your learning of mathematics.

If you decide to be part of this study, you may be video-taped while you use technology to solve mathematics problems. You will talk to me about your experiences during a one to one interview time. These interviews will be audio-recorded. Also, you will allow me to watch you and take notes while you are solving these problems. Your participation in this project will not affect your grades in school. I will not use your name on any papers that I write about this project. However, because of your participation you may improve your ability to solve mathematics problems and use technological tools to your advantage. I hope to learn something about using technology to solve mathematics problems that will help other children in the future.

If you want to stop participating in this project, you are free to do so at any time. You can also choose not to answer questions that you don't want to answer. If you have any questions or concerns you can always ask me or call my teacher, Dr. Jim Wilson at the following number: 706 542 4194.

Sincerely,

Jacob Thomas Klerlein (Jake)

Department of Mathematics Education

The University of Georgia

105 Aderhold Hall

Athens, GA 30602

706 542 4194

jklerlei@coe.uga.edu

I understand the project described above. My questions have been answered and I agree to participate in this project. I have received a copy of this form.

____

Signature of the Participant/Date

Please sign both copies, keep one and return one to the researcher.

For additional questions or problems about your rights as a research participant please call or write: Chris A. Joseph, Ph.D., Human Subjects Office, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, GA 30602-7411; Telephone (706) 542-3199; E-mail Address: IRB@uga.edu

APPENDIX 5

Principal Consent Form

12/7/2004

To Whom It May Concern:

I agree to allow Mr. Jacob Klerlein to conduct the study, "Student affect during mathematical problem solving," in Social Circle Middle School. I am aware of the methodological choices to be implemented in the study as well as the goals of the research. I have viewed the student assent and parental consent forms and believe they are appropriate for the intended purposes.

Sincerely,

Paula M. Griffin, Principal

Social Circle Middle School

APPENDIX 6

Interview Protocol (Specific Instance)

1. Tell me about the problem that you worked with today.

2. Do you thinking that using technology was necessary in order to solve this problem? Follow up to this response.

3. Let's talk about your feelings that you experienced while working on this problem. Follow up to this response will lead to a participant's discussion of the role these emotional responses had in motivating further efforts or stalling activity.

4. What parts of your work today were original and not necessarily required by the problem? How did the technology influence your work.

APPENDIX 7

Interview Protocol (End of Year)

Let’s start by just talking about you. Talk to me about things you like and things you don’t like.

Let’s talk about math class this year and how it was like other math classes you have been in and how it was different.

Where else in school do you use technology? How about outside of school?

Was using technology in our class worthwhile? How did you figure out what to do with the computer?

APPENDIX 8

Prior research transcript

Interviews I have conducted with middle grades students suggest this role of technology is important and valued by students.

J: … do you think that using technology was necessary to solve this problem?

Chris: yes

J: tell me why please

Chris: *because it would have been a pain trying to figure all that out on paper*.

J: how would that have been a pain?

Chris: it would just take forever…

J: do you think that maybe you would have tried to do it a different way if you had done with paper and pencil or you probably would have done it the same way?

Chris: well I couldn't like type in a formula, it would just be harder. Excel is easy to use and you get the same thing, *but you are thinking about the problem instead of doing all these little bitty things*, like ahh I forgot to carry my two and etc.

Here Chris articulated that having access to such a technology tool allowed him to concentrate on aspects of the problem he would have not attended to as coherently if he did not have the computational support of Excel. Similarly Cassandra related her ideas about using technology tools while trying to solve a problem.

J: what do you think Cassandra? Do you need technology to do this problem?

Cassandra: I don't need it, but it is better to use

J: can you tell me a little bit about why it is better?

Cassandra: …, I don't know how to describe it but it is easier to do with excel

J: what part of the math does it do for you?

Cassandra: the adding subtracting multiplication

J: OK so it does the computation for you

Cassandra: yea, that is the word

J: if it does the computation for you, does that mean you can just be lazy and not have to do anything?

Cassandra: *NO*

J: …, you would rather think about what the formula is rather than doing computation

Cassandra: basically

J: even though it might be harder to think about?

Cassandra: it is not that harder to think about because when you are doing computation if the teacher doesn't let you use a calculator then you have to do mental math and write things out and with excel you can just go ahead and type it and *do what you have to do*. (March 21, 2003).

By paying attention to the comments that have been italicized, one gets a sense of how these two middle grade students valued the opportunity to allow their thinking to be focused on what the problem was asking rather than what they viewed as the mundane computations that had to be carried out to find a solution.

APPENDIX 9

Final Project

Topic: What you want to know more about AND the mathematics related to that topic.

Oral Presentation:

- Demonstrate knowledge of the topic and the mathematics related to the topic
- Include visual aids such as posters, models, videos, or powerpoint presentations
- Keep good eye contact, speak clearly, and have strong posture
- All group members must participate

Written Aspect:

- Focuses largely on the mathematics
- No more than two written pages
- Use correct grammar
- Include some graphs, tables, charts, and/or figures
- Typing is optional, but preferred