ABSTRACT

DOVE, ANTHONY MICHAEL. Teaching Geometry in a 1:1 Classroom: High School Teachers' Instructional Practices while Participating in Professional Development. (Under the direction of Dr. Karen Hollebrands).

Technology has become an ever-present part of the United States society. Initiatives are working to make technology ubiquitous in schools as well. Prior research suggests that learner-centered technology-enhanced lessons support student engagement, motivation, and achievement in learning mathematics. Research also suggests that without providing extensive professional development and training, teacher implementation of learner-centered technology-enhanced lessons may be limited.

While there is extensive research on instructional practices, general use of technology in mathematics classrooms, and general professional development, little research has been conducted that explores the influence of 1:1 initiatives, the professional development needed in these initiatives, or the changes that may occur in teachers' classrooms while implementing such initiatives. This study examined the instructional practices and technology integration of Geometry teachers in 1:1 classrooms changed while participating in long-term professional development that emphasized using *The Geometer's Sketchpad* to enhance instructional activities. A collective case study design was used to examine individual teachers' instructional practices and technology integration through the first semester following the Summer Institute of a two-year face-to-face and online professional development program. Cross-case analysis was used to identify themes of challenges and supports among the participants for teaching in technology-enhanced classrooms.

Findings from this study suggested that all teachers in this study incorporated technology into more lessons than previous years, students were more engaged when participating in *GSP* activities, and the cognitive demand and student discourse was typically greater in *GSP* activities than other activities in a lesson. Four common challenges and three supports emerged from the cross-case analysis. Challenges included issues of time, learning *The Geometer's Sketchpad* (*GSP*) and its limitations, scaffolding *GSP* activities, and learning how to support student discourse. Supports included successful implementation of *GSP* activities, on-going professional development, and the emergence of a colleague support system. The findings from this study suggest that on-going professional development can provide opportunities for change in instructional practices and technology integration. This study also suggests that teacher collaboration both in and out of professional development opportunities can influence such changes as well.

Teaching Geometry in a 1:1 Classroom: High School Teachers' Instructional Practices while Participating in Professional Development

by
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DEDICATION

Emily, you have been there through it all. You supported me in pursuing my doctorate. You encouraged me when I struggled, and you celebrated with me each accomplishment along the way. I will be forever grateful of your sacrifice, your faith in me, and your love. Anna, you are my continual sunshine on even the toughest days. You provided me with the motivation to complete my doctorate so that I can be the father you deserve. Mom and Dad, I doubt that I would have my drive and determination without you. From an early age, you have loved and supported me and instilled in me the importance not only of education, but in helping others. While you always say how proud you are of Adam and I, know that I am proud to be your son. Adam, this journey began at an early age of following in your footsteps and led me into a career in Education. I could not ask for a better brother in the world.

I am proud to call each of you my family. I love you and dedicate this to you.

BIOGRAPHY

Anthony Michael Dove was born in Mt. Jackson, Virginia on March 29, 1982. After graduating from Stonewall Jackson High School in Quicksburg, Virginia, he enrolled at the University of Richmond in Richmond, Virginia in 2000 where he earned a Bachelor's of Arts degree in Mathematics with a minor in Secondary Education.

In 2003, Anthony accepted a position teaching 8th grade mathematics and Algebra I at Bailey Bridge Middle School in Midlothian, Virginia. In 2004, Anthony's interest in using technology to teach mathematics led him to accept a position Deep Run High School in Glen Allen, Virginia, which was a 1:1 high school. During his four year tenure, Anthony taught Algebra I part 1, Geometry (Standard and Honors), Algebra II, and Honors Precalculus. While teaching at Deep Run, Anthony completed his Master's of Education in Mathematics Education at the University of Virginia in 2008.

In 2008, Anthony left Deep Run to pursue his Doctorate in Mathematics Education at North Carolina State University. While completing his PhD, Anthony worked as a Graduate Research Assistant on the North Carolina 1:1 Learning Collaborative and the SMART Classrooms grant at the Friday Institute for Educational Innovation. In these programs, Anthony was involved in planning, creating, and implementing face-to-face and online professional development opportunities for teaching and learning in technology-enhanced learning environments.

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CHAPTER 1

Technology in Society

Technology has become an integral part of the United States society. A 2007 survey from the US Census Bureau showed that just under 71 percent of children ages 3 – 17 lived in homes with internet access (Edwards, 2009). This did not include digital mobile devices which have become just as ubiquitous within children's lives. The Pew Internet & American Life Project (Lenhart, 2009) similarly found that of the adolescent population (ages 12 to 17), 71% had cell phones, 77% had a game console, and 74% had a digital music device. These numbers increased as students moved into high school with at least 84% of adolescents having a cell phone by age 17. Moreover, this project found that whether a computer was in the home or not, 93% of teens from ages 12 to 17 go online on a regular basis. Prensky (2001) labeled this generation of children as "digital natives" because they were born into a technologically advanced world. However, the amount of technology within the schools that these students attend and how the available technology is integrated into the classroom varies dramatically from district to district and even school to school. Classes are being taught by teachers whom Prensky labeled as "digital immigrants" as they were not born into this technologically advanced world, and thus they may not understand or value how the digital native students learn. Prensky suggested, "The single biggest problem facing education today is that our digital immigrant instructors, who speak an outdated language (that of the pre-digital age), are struggling to teach a population that speaks an entirely new language" (p. 2).

Educating digitally-active students is imperative to improving the number of graduates that are qualified to begin careers in a technology-enhanced society (Dede, Korte, Nelson, Valdez, & Ward, 2005). This has become even more necessary as the number of technology-based job opportunities continues to increase in the STEM-related areas. In the 2011 State of the Union Address, President Obama suggested that "in a single generation, revolutions in technology have transformed the way we live, work and do business" (Obama, 2011, para. 17). Other countries have used this technology revolution to invest in the STEM-related fields as well as place an emphasis in education to include more instructional time for mathematics and science classes. To remain globally competitive, Obama suggested that we be cognizant of these countries as well as learn from our past.

> Half a century ago, when the Soviets beat us into space with the launch of a satellite called Sputnik, we had no idea how we would beat them to the moon. The science wasn't even there yet. NASA didn't exist. But after investing in better research and education, we didn't just surpass the Soviets; we unleashed a wave of innovation that created new industries and millions of new jobs. This is our generation's Sputnik moment. (para. 26)

However, current trends show that the number of students receiving higher education degrees in the STEM-related areas has been declining (Friedman, 2005). To alter this current trend, changes need to occur within the classroom to help engage and motivate students so that they become interested once again in pursuing careers in STEM-related areas.

Influence of Technology on Students in the Classroom

One possible strategy for increasing the number of students pursuing STEM-related careers is to integrate technology into the mathematics classroom. Studies which have investigated the influence of technology integration into mathematics classrooms have found that students were often more engaged in classroom activities, showed greater motivation for learning, and had significantly greater growth in learning (Baharvand, 2001; Burkhead, 1998; Dixon, 1995; Freeman & Crawford, 2008; Mouza, 2008; Yousif, 1997; Ysseldyke, Tardew, Betts, Thill, & Hannigan, 2004). Also, integrating technology into instruction has shown to help improve differentiated instruction (Dixon, 1995; Freeman & Crawford, 2008; Tran, 2005; Ysseldyke et al., 2004). For instance, English Language Learners (ELL or ESL) students can use computer software that provides scaffolding to not only learn the mathematics, but to also help them transition from learning mathematics in their native language to English. This has shown significant positive increases not only in math scores but also in English proficiency (Dixon, 1995; Tran, 2005; Freeman & Crawford, 2008). Other software programs such as intelligent tutoring programs and curriculum-based instruction management systems like *Accelerated Math* (Renaissance Learning, 1998) measure student strengths and weaknesses to automatically reprogram lessons based upon student responses to provide appropriate instruction. This form of instruction has also shown positive significant achievement gains for all students, especially high achieving students in differentiated classroom settings (Ysseldyke et al., 2004).

Within the Geometry classroom, a unique set of programs known as dynamic geometry environments (DGEs) (e.g.- *Geometer's Sketchpad* (*GSP*) (Jackiw, 2010)) offer students the opportunity to explore, conjecture, discover, and experiment in ways that are not available with only pencil and paper (Jones, 2000; Marrades & Guittierez, 2000; Pitta-Pantazi & Christou, 2008). DGEs provide features that allow for extensive and instantaneous manipulation like measuring and dragging which let “students see as many examples as necessary in a few seconds, and provide them with immediate feedback that cannot be obtained from paper-and-pencil teaching” (Marrades & Guittierez, 2000, p. 119). By using DGEs, students are able to enhance their exploration of relationships, which has been shown to lead to improved conjectures and a shift from empirical to deductive justification when solving problems (Burkhead, 1998; Hollebrands, 2007; Jones, 2000; Marrades & Gutierrez, 2000). These enhanced reasoning processes have also been shown to translate into increased student learning both within a single instructional unit and across an entire year. Several studies have suggested that students in classes that used DGEs not only had significantly greater gains in researcher-created assessments that served as end of unit tests (Baharvand, 2001; Dixon, 1995; Yousif, 1997), they also had significantly greater scores on state end-of-course exams in comparison to students who did not experience use of DGEs in class (Myers, 2009).

Teacher Use of Technology in the Classroom

Although studies have suggested that technology can influence students’ motivation, engagement, and achievement, this does not always translate into increased use of technology in the classroom. One reason may be that change towards ubiquitous use of technology in the classroom is not an easy task. Zbiek, Heid, Blume, & Dick (2007) suggested that a teacher’s understanding of the pedagogical fidelity of a technological tool may determine if and when technology is incorporated. They defined pedagogical fidelity as “the extent to which teachers (as well as students) believe that a tool allows students to act mathematically in ways that correspond to the nature of mathematical learning that underlies a teacher's practice” (p. 1187). For example, if a teacher wishes to incorporate investigation and inquiry into his/her instructional practices, he/she may value software and tools that facilitate student investigation of the mathematical concepts being learned.

An increase in the use of technology does not always relate to appropriate or quality usage of technology for teaching and learning (Lei & Zhao, 2007). Research suggests that digital tools and resources may be best implemented in classrooms when pedagogical practices shift towards learner-centered instructional practices and emphasizes inquiry-based learning, student collaboration, and active discourse among all members of the classroom (Borko, Stecher, Alonzo, Moncure, & McClam, 2005; Piburn, Sawada, Turley, Falconer, Benford, Bloom, & Judson, 2000). Nelson, Christopher, and Mims (2009) suggested, “True technology integration is a thoughtful approach in which teachers understand how to relate concepts with technologies, demonstrate creative pedagogical practice, and facilitate technology use in ways to teach content and skills with a student centered approach” (p. 82).

The 1:1 Classroom

To continue to enhance the integration of technology into the schools, an increasing number of districts and states are implementing 1:1 classroom environments. An emphasis of 1:1 initiatives has been to help students leave school with the 21st century skills needed to become active members in a technology-enhanced society (Warschauer, 2006; Weston & Bain, 2010). In 1:1 learning environments, every student and teacher is provided a digital wireless device which has current applicable software for meeting a district's teaching and learning goals and access to the internet at school (Muir, Manchester, & Moulton, 2005; Penuel, 2006).

Studies have suggested that 1:1 classroom environments can have positive influences on students. These have included improved attendance (Lane, 2003), decreased disciplinary problems (Bebell, 2005), and increased classroom engagement (Bebell & Kay, 2010; Warschauer, 2006). Silvernail & Lane (2004) found that students felt that the laptops helped them stay more organized, made completion of work more efficient, and felt the quality of their work improved. However, achievement results have been mixed where some studies have shown improvements in student achievement (Dove, 2011; Shapley, Sheehan, Maloney, & Carnikas-Walker, 2010; Suhr, Hernandez, Grimes, & Warshauer, 2010) while others have shown no difference or a negative effect on achievement (Mann, 2008; Warschauer, 2006; Weston & Bain, 2010).

Professional Development that Supports Technology-Enhanced Instruction

Having access to the technology such as DGEs and laptops in 1:1 initiatives does not ensure teachers' instructional practices will shift, nor does it guarantee that they will use laptops in their lessons and activities (Warschauer, 2006). For this to occur, teachers need to participate in professional development that can help them effectively incorporate technology into their lessons and instructional practices (Corn, 2009; Penuel, 2006; Silvernail & Lane, 2004; Weston & Bain, 2010). Research has suggested that this professional development must include four components to influence change: extended time, content-specific training, learner-centered instructional practices for the professional development, and coherence throughout the professional development experience (Darling-Hammond, Wei, Andree, Richardson, and Orphanos, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, Gallagher, 2007; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007)

First, the professional development should span at least 30 hours of training and a minimum duration of six months (Darling-Hammond et al., 2009; Garet et al., 2001; Yoon et al., 2007). However, extended time is not enough. As Guskey (1999) stated, "If the additional time for professional development is to yield truly meaningful improvements, we must ensure that time is used wisely, efficiently, and effectively" (p. 11). The quality of the experiences is as important as the amount of time spent within the professional development. One such quality requirement is that the professional development should be inherently content-specific (Darling-Hammond et al., 2009; Garet et al., 2001; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2009). Professional development educators must also model learner-centered instructional practices so that participants are actively engaged and learning throughout the entire experience. Finally, coherence must exist within the professional development. Aspects of coherence include: connections to teaching goals and other activities in the overall professional development; alignment with district, state, and national standards and assessments; and types of communication with the instructors and other participants both during and after the event (Darling-Hammond et al., 2009; Garet et al., 2001; Yoon et al., 2007). These four requirements are especially necessary for professional development in technology-enhanced learning environments. Harris, Mishra, and Koehler (2007) stated:

> Technology integration approaches that do not reflect disciplinary knowledge differences, and the corresponding processes for developing such knowledge, ultimately are of limited utility and significance, ignoring as they do the full complexity of the dynamic realities of teaching effectively with technology (p. 4).

With research-based professional development suggesting that content-specific training is needed to provide optimal learning opportunities for participants, one must consider which content matter may provide an optimal learning situation for integrating technology into the classroom. Within mathematics, Geometry offers an optimal teaching medium due to its visual nature with opportunities to explore mathematical topics using points, lines, planes, shapes, and solids. DGEs like *GSP* offer an opportunity to transform basic static visualization into something that can be touched, moved, and manipulated (Jones, 2000; Marrades & Guittierez, 2000; Pitta-Pantazi & Christou, 2008). With content-specific software programs available, Geometry presents a unique opportunity to provide the appropriate scaffolding teachers may need to make the transition to effectively using technology in the classroom (Niess et al., 2009). DGEs also allow teachers to experiment with new pedagogical practices that are more learner-centered as these programs lend themselves to incorporating more inquiry, discovery, exploration, and collaboration (Jones, 2000; Marrades & Guittierez, 2000; Pitta-Pantazi & Christou, 2008).

Studies have also shown that with effective professional development and experience in 1:1 environments, teacher's instructional uses of technology and pedagogical practices begin to shift. Corn (2009) found that teachers' use of laptops significantly increased over time. In particular, teachers used the laptops during lessons to provide instruction, assess student understanding, present activities, and utilized more online opportunities like virtual field trips and content-specific websites. Studies have also found that teachers in 1:1 environments transition to using more learner-centered instructional practices, such that their lessons include more inquiry-based learning (Cavanaugh et al., 2007; Fairman, 2004: Lowther et al., 2008), collaborative learning opportunities (Cavanaugh et al., 2007; Fairman, 2004; Lowther et al., 2008; Peck et al., 2008), and use of differentiated instruction (Fairman, 2004; Mitchell Institute, 2004; Silvernail & Lane, 2004).

Purpose of Study and Research Questions

This study was motivated by the possibility that technology-enhanced mathematics classrooms may provide a more engaging learning experience for students, which may lead to a greater interest in STEM-related fields. We know that for technology to be effectively integrated into the mathematics classroom, meaningful long-term professional development is needed. For these reasons, the purpose of this study was to examine and explore teachers' instructional practices and integration of technology while participating in face-to-face and online professional development. Specifically, this study examined the following questions:

1. What is the nature of Geometry teachers' technology integration and instructional practices in a 1:1 classroom environment?
2. What commonalities do Geometry teachers share regarding their pedagogical practices?

Summary

Technology has become an integral part of life in the United States. As technology has become ubiquitous outside of schools, various programs and initiatives have been launched in schools to make technology become a regular part of classroom instruction. Professional development may provide a needed support to help teachers learn how to effectively incorporate technology-enhanced lessons. The following chapter will further examine effective research-based instructional practices for mathematics teachers, how technology can be incorporated to enhance these practices, and the role professional development may have in supporting the integration of technology into research-based instructional practices.

CHAPTER 2

Literature Review

This study examined teachers' instructional practices and technology integration while participating in long-term professional development centered on teaching geometry with *GSP* in a 1:1 classroom environment. Additionally, the study explored what issues may have influenced the instructional practices and integration of technology into the classroom. Prior research was explored to identify best practices for teaching and learning in technology-enhanced mathematics classrooms, challenges teachers face in implementing these practices, and how professional development may be able to help teachers regularly incorporate such instructional practices for teaching and learning into their classrooms.

Instructional Practices

Instructional practices are the methods and techniques used to present information to students and are primarily categorized as either teacher-centered or learner-centered (Artzt & Armour-Thomas, 1999; O'Bannon, 2002; Phillips, 2005; Weimer, 2002). Teacher-centered practices emphasize the teacher presenting information and directing learning that occurs during class. Additionally, "the teacher identifies the lesson objectives and takes the primary responsibility for guiding the instruction by explanation of the information and modeling. This is followed by student practice" (O'Bannon, 2002, para. 2). Examples of teacher-centered practices include lecture, lecture discussions, teacher demonstrations, and direct instruction, among others. Lecture and direction instruction are considered different teacher-centered practices. Direct instruction includes a regimented technique for teaching where the teacher begins with an introduction or review of previous material, conducts a lecture on new material, leads guided practices, and concludes with independent practice, whereas lectures are based on the teacher presenting new material during the entire lesson while students listen and take notes.

In contrast, learner-centered practices emphasize the teacher facilitating the learning process so that students can construct their own understanding from the lesson (Artzt & Armour-Thomas, 1999; O'Bannon, 2002; Phillips, 2005; Weimer, 2002).

> Being learner-centered focuses attention squarely on learning: what the student is learning, how the student is learning, the conditions under which the student is learning, whether the student is retaining and applying the learning, and how current learning positions the student for future learning. (Weimer, 2002, p. XVI)

A plethora of learner-centered practices exist such as cooperative learning, discovery learning, inquiry-based learning, learning centers, and problem-based learning (O'Bannon, 2002).

Instructional Practices for Mathematics

Instructional practices vary greatly within mathematics classrooms. In 1991, the National Council of Teachers of Mathematics (NCTM) created the *Professional Standards for Teaching Mathematics* (*PSTM*) (NCTM, 1991a) to provide recommended best instructional practices that support student learning in mathematics classes. *PSTM* stated:

> The image of mathematics teaching needed includes elementary and secondary teachers who are more proficient in
>
> - Selecting mathematical tasks to engage students' interests and intellect;

- Providing opportunities to deepen their understanding of the mathematics being studied and its applications;
- Orchestrating classroom discourse in ways that promote the investigation and growth of mathematical ideas;
- Using, and helping students use, technology and other tools to pursue mathematical investigations;
- Seeking, and helping students seek, connections to previous and developing knowledge;
- Guiding individual, small-group, and whole-class work. (para. 2)

These ideas led to the creation of six standards for teaching mathematics: Worthwhile Mathematical Tasks, Teachers' Role in Discourse, Students' Role in Discourse, Tools for Enhancing Discourse, Learning Environment, and Analysis of Teaching and Learning.

The six standards in *PSTM* emphasized learner-centered instructional practices so that teachers would actively engage students in meaningful mathematical tasks that promote inquiry and discourse in a collaborative learning environment (NCTM, 1991b). Since the publication of *PSTM*, research both in mathematics education and other fields have supported the shift towards more learner-centered practices. Lang and McBeath (1992) suggested that people retain only 5% of a lecture and 30% of demonstrations whereas retention is greater for group discussion (50%), individual practice (75%) and teaching others (90%). In teaching Physics at MIT, Dr. Walter Lewin provided well-renowned eccentric demonstrations and lectures, yet attendance rates averaged only 50% with a failure rate of over 10% (Belcher, 2003). This led to the creation of a learner-centered instructional approach called TEAL

(Technology Enhanced Active Learning). TEAL classes provided interactive, inquiry-based classes where students worked with the professor to solve complex real-world problems. During the first three years of the program, student achievement and attendance were consistently significantly greater in TEAL classes than in the corresponding traditional lecture classes. Similar results were found in a study by Deslauriers, Schelew, and Wieman (2011) in which a college physics class taught by two untrained graduate students using learner-centered practices had significantly greater attendance, achievement scores, and student enjoyment of class than a lecture-based class taught by an experienced professor.

Within mathematics education, the six standards of *PSTM* provided support for what some researchers have called reform-oriented mathematics teaching (Borko et al., 2005; Kurz & Kokic, 2008; Silver, Mesa, Morris, Star, & Benkin, 2009). While the definition of reformed teaching varies between authors and studies, the general premise of the reform movement entails helping teachers integrate more learner-centered practices into their instruction (Borko et al, 2005; Kurz & Kokic, 2008; Piburn, Sawada, Turley, Falconer, Benford, & Bloom, 2000; Sawada et al., 2002). Research has supported this emphasis on increasing learner-centered practices in mathematics instruction. Lawson et al. (2002) found a strong significant positive correlation between professors who used learner-centered practices in teaching an undergraduate mathematics class and student achievement ($r = .92$, $p < .001$). Judson and Sawada (2001) found that teachers who participated in a greater number of classes as an undergraduate in which the professors used learner-centered practices were significantly more likely to use learner-centered practices in their teaching of middle and high school mathematics. In examining the applications of a random sample of 32 teachers who applied for the mathematics National Board certification, Silver (2010) found that teachers who received National Board certification had significantly more high cognitive demand tasks and were more consistent in their use of learner-centered instructional practices than teachers who were not certified.

Utilizing research-supported learner-centered practices requires teachers to look at several components of instruction, such as the lessons' activities and the general classroom environment. *PSTM* stated, "Tasks provide the stimulus for students to think about particular concepts and procedures, their connections with other mathematical ideas, and their applications to real-world contexts… Tasks also convey messages about what mathematics is and what doing mathematics entails" (NCTM, 1991b, para. 1). In recognizing the importance of tasks in student learning, Stein and Smith (1998) created a framework for teachers to help them reflect on what students were thinking and doing within an activity. This framework included four levels of cognitive demand for a task: Memorization, Procedures without Connections, Procedures with Connections, and Doing Mathematics. With memorization tasks, students reproduce facts, rules, formulas, etc. with no underlying meaning being applied to the activity. With procedures without connections tasks, students solve algorithmic tasks that follow similar patterns to those provided during instruction, provide no explanations for their work, and do not work on connecting the algorithm with the underlying mathematical relationship(s). With procedures with connections tasks, students work to develop understanding between procedures and mathematical relationships and often are required to use multiple representations to make those connections. Finally, doing mathematics tasks are characterized by students being required to use complex thinking since the tasks are nonalgorithmic. These tasks may have multiple methods and multiple solutions and require students to explore the connection among mathematical relationships of multiple concepts.

Cognitive demand has also been examined by other researchers. For example, Marshall and Horton (2011) analyzed over 100 observations of middle school science and mathematics teachers to explore how the level of inquiry-based practices influenced the cognitive demand of tasks. Observations were coded using the Electronic Quality of Inquiry Protocol (EQUIP), which measured 19 indicators in four constructs (instruction, discourse, assessment, and curriculum). For this study, three specific indicators were analyzed using Pearson's correlations. These were Components of Inquiry, Cognitive Levels of Demand, and Order of Instruction. Significant correlations between Components of Inquiry and Cognitive Levels of Demand suggested that for all grades and subjects, as the amount of student exploration in the class increased, the cognitive demand of tasks increased as well ($r = .54$, $p < .001$). Additionally for the mathematics teachers of the study, there was a significant correlation between the amount of time a teacher spent in Order of Instruction area of Explanation and the lowest measured Cognitive Demand Level ($r = .54$, $p < .001$). Marshall and Horton summarized:

> If reasoning and critical thinking are instructional goals, then these results suggest that teachers should consciously provide opportunities for students to develop the ideas for themselves. In our observations, this did not equate to free discovery time, but rather to guided Exploration time in which students were given parameters by which to Explore the concepts. (p. 99)

The struggle for teachers to maintain high cognitive demand of mathematical tasks was also observed by Stigler and Hiebert (2004) in their analysis of the 1995 and 1999 TIMSS data. In examining the mathematical problems asked by United States 8th grade teachers that participated in TIMSS, Stigler and Hiebert found that 69% of the problems posed were of low cognitive demand with a focus on using procedures while only 17% of the problems posed were of high cognitive demand with emphasis on making mathematical connections. However, when the mathematical connections problems were further examined, Stigler and Hiebert found that "teachers implemented none of the *making connections* problems in the way in which they were intended. Instead, the U.S. teachers turned most of the problems into procedural exercises or [they] just supplied students with the answers to the problems" (p. 15).

Planning high demand mathematical tasks does not ensure that they will be implemented as such (Stein & Smith, 1998; Stigler & Hiebert, 2004). Much of the success or failure for the implementation of high demand tasks involves the classroom environment and the discourse which takes place in this environment. Unlike learner-centered methods of discourse which emphasize student collaboration and engagement in discussion, many teachers predominately use the Initiation-Response-Evaluation (IRE) pattern for discourse (Franke, Kazemi, & Battey, 2007; Sherin, 2002). With this method, the teacher provides questions to which a student replies only with the solution. This response is then evaluated by the teacher for correctness before proceeding. While IRE allows teachers to quickly cover material, it often is completed using low demand tasks that do little to engage students or determine their conceptual understanding. Teachers that use IRE build a classroom culture where the students are expected to follow the rules, attain knowledge from the teacher, and show understanding by remembering and applying concepts to teacher questions (Lampert, 1990). Through student interviews, Franke et al. (2007) found that IRE pattern for discourse influenced students' beliefs of what it meant to do mathematics from an early age. For example, interviewed first graders typically did not expect student discussion to be part of the regular class routine. Instead, students stated that their role in discussion was to provide the solution to the teacher when called upon. They also expected follow-up questions to only occur when their solution was incorrect. "They knew their answer was wrong if the teacher asked them a question about it… And student responses within classrooms were quite consistent" (p. 238).

Although the IRE pattern may be prevalent in many mathematics classrooms, teachers are beginning to employ learner-centered instructional practices. Often this is done through a combination of high demand, collaborative, exploratory activities followed by whole class discussion that includes students sharing multiple methods and/or solutions for the tasks (Lampert, 1990; Stein, 2007; Stein et al., 2008). For instance, Sherin (2002) observed an 8^{th} grade mathematics teacher for two years while he worked to improve his balance of classroom discourse. In lessons that had high student engagement, the teacher often used four questions: What do you think?; Why?; What do others think about that?; and Can you explain that? These four questions moved evaluation away from the teacher and to the students as they had to not only provide solutions but also provide explanations for how the solution was found and why it was mathematically correct. These questions also provided students with the opportunity to analyze and critique each other’s work with the focus being on understanding the process for solving the problem, not on the solution.

Although student discourse is an important aspect of classroom instruction, simply having students talk to one another is not sufficient. Rather teachers have to help focus and guide mathematical discussions for students to build mathematical understanding (Franke et al., 2007; Sherin, 2002). In this role, the teacher serves as a filter for mathematical discourse. Sherin (2002) stated:

> This filtering approach can serve both process and content goals. In terms of process, the students have a great deal of opportunity to share their thinking and the teacher’s “filtering of ideas” is based on the ideas that students raised. Yet at the same time, this approach also enables the teacher to exert some control over the mathematical direction of the lesson. (p. 227 – 228)

When teachers successfully filter discourse, students are provided opportunities to talk and explore each other’s solutions while well-timed questions from the teacher help guide student thinking toward a collective understanding of the topics being learned within the lesson (Cobb et al., 1997; Hufferd-Ackles, 2004).

However, lack of filtering by the teacher has the potential to decrease the mathematical nature of the discourse and lead students to confusion and misconceptions (Sfard, 2000). Nathan and Knuth (1997) observed a 6^{th} grade teacher for two years. During the first year, the teacher‘s discourse primarily followed the IRE pattern as she limited student discourse within her class. The following year, the teacher worked to increase student discourse. To do so, the teacher removed herself as the central mathematical authority and moved to a role of moderator. While student discourse substantially increased, competing ideas were often not addressed as the teacher did not providing any filtering. In several cases when students were confused or unsure of the correct method or solution, the teacher did not provide scaffolding to help guide them towards building their solutions through argument, justification, and reasoning. Instead, students voted between methods or solutions, even when the students could not provide reasoning behind their method or solution that was chosen. Nathan and Knuth summarized, “Discourse of this nature does not come about simply because the teacher creates the space for it; there is still a need to mathematically support students' learning of content during classroom interactions” (p. 203).

Part of the reason why teachers struggle in implementing learner-centered instructional practices may be due to lack of administrative support. While interviewing 21 rural principals in Ohio, Howley, Larson, Solange, Rhodes, and Howley (2007) found that although 19 stated that they were familiar with learner-centered instructional practices, their views were often superficial. Most recognized that these practices emphasized meaningful learning instead of memorization or direct application of algorithms, but they were often vague as to how it was being implemented within their schools. Moreover, less than one-third of the principals discussed the need for real-world applications, and only one-fourth mentioned the incorporation of inquiry-based learning. Half of the principals felt that the textbooks served as the true curriculum, thus they stated that finding the correct textbook that suggested practices like inquiry-based learning would change the classroom culture. At the same time, the principals suggested that teachers were working to incorporate pedagogical changes within their classes such as student collaboration, use of technology, and incorporating high-order questions into activities and assessments. As a result, since these pedagogical changes "represented modest adjustments rather than radical departures from past practice…the mathematics education reforms adopted by these schools were becoming institutionalized in almost all cases" (p. 9).

Spillane & Zeuli (1999) found similar results when observing and interviewing 25 elementary and middle school mathematics teachers in nine districts recognized for instructional innovation in Michigan. Of the 25 mathematics teachers, 21 felt comfortable with the *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), the Michigan mathematics education standards, and instructional practices suggested in *PSTM*. However, only four teachers fully embraced these learner-centered instructional practices within their mathematics instruction. The researchers suggested that "it was the mathematical tasks and the discourse patterns [in these four teachers' classes] that distinguished their practice from the practice of others in our sample" (Spillane & Zeuli, 1999, p. 7). These teachers had students create and defend solutions to problems, facilitated the exposure of key mathematical ideas, and were constantly pushing for increased student mathematical discourse within their classes. Another 10 teachers worked to incorporate some learner-centered practices such as using complex tasks and student collaboration. However inclusion of student discourse was minimal as teachers often asked for solutions without justification. The final 11 teachers primarily used terminology mentioned in the six standards of *PSTM* to rename the traditional practices that they continued to use within their classes. While students worked in groups on problems using manipulatives or available technology, the general instructional practices remained teacher-centered with an emphasis in gaining procedural knowledge to solve computational problems. Spillane & Zeuli concluded, "Teaching is a multidimensional practice, and our analysis suggests that some dimensions of that practice appear to be more responsive to reform than others" (p. 19).

Teachers' instructional practices can influence the tasks provided, the cognitive demand of the activities, the discourse involved, and the overall learning environment for the students. Research has suggested, lessons should be planned to include tasks that are of high cognitive demand and provide opportunities to participate in student discourse, make connections between mathematical topics, and integrate real-world applications (Hufferd-Ackles, 2004; Judson & Sawada, 2001; Lawson et al., 2002; Sherin, 2002; Silver et al., 2009). Implementation of these lessons should have teachers facilitating and filtering student exploration, collaboration, and discussion. Stein (2007) stated, "If all students are to be engaged, teachers must foster classroom discourse by providing a welcoming community, establishing norms, using supportive motivational discourse, and pressing for conceptual understanding" (p. 288).

Technology in the Mathematics Classroom

The integration of digital tools and resources may provide an opportunity for teachers to support students' learning of mathematics through exploration, discussion, and engagement. In the *Principles and Standards for School Mathematics* (*PSSM*) (NCTM, 2000), the use of technology in mathematics was recognized as one of the six fundamental principles.

> Calculators and computers are reshaping the mathematical landscape, and school mathematics should reflect those changes. Students can learn more mathematics more

> deeply with the appropriate and responsible use of technology. They can make and test conjectures. They can work at higher levels of generalization or abstraction. In the mathematics classrooms envisioned in *Principles and Standards,* every student has access to technology to facilitate his or her mathematics learning. (para. 1 - 2)

This claim for the utility of technology in the classroom by *PSSM* continues to be supported by research, especially around the use of dynamic geometry environments (DGEs) with students from elementary to high school mathematics (Baharvand, 2001; Burkhead, 1998; Choi-Koh, 1999; Dixon, 1995; Hollebrands, 2007; Jones, 2000; Marrades & Guittierez, 2000; Mouza, 2008; Myers, 2009; Yousif, 1997). DGEs are software programs that allow students to explore mathematical relationships in a dynamic manner. For instance, if a student constructs a right triangle in a DGE, the constructed right angle will remain right no matter how the triangle is dragged or manipulated. Baharvand (2001) found that *The Geometer's Sketchpad* (*GSP*) not only increased student achievement in several 7th grade geometry units (polygons, area, and ratio and proportion), but it also increased student engagement, motivation, and attitudes towards technology. In this mixed methods study, Baharvand taught one class with direct instruction, which included lecture, guided practice, independent practice, and several paper-and-pencil activities, while the second class used *GSP* to complete structured independent investigations and explorations. For some complex constructions and concepts, teacher-guided demonstration was provided. Each *GSP* lesson ended with a class discussion on the topics learned from the day's activities. A pretest-posttest assessment showed that the *GSP* class had a significantly greater improvement in the geometry unit and had significantly greater retention of material on open-ended questions when retested a month later. Additionally, classroom observations showed that "the computer setting and technology environment [seemed] to encourage good student behavior… Students' work became more accurate and their ability to express observations correctly and concisely improved" (p. 37). Other studies have found similar positive results in student achievement on researcher-created assessments (e.g., Dixon, 1995; Hannafin, Burruss, & Little, 2001; Yousif, 1997) as well as the Florida Geometry end-of-course exam (Myers, 2009).

In addition to increases in student achievement, DGEs can also improve student explanations, deductive thinking, and justification skills (Burkhead, 1998; Hollebrands, 2007; Jones, 2000; Marrades & Gutierrez, 2000). For example, Jones (2000) found that DGEs improved student reasoning and explanations of geometric relationships within the topic of quadrilaterals. In his study, Jones followed four pairs of students throughout the course of the school year as they used *Cabri I* to complete three modules centered on quadrilateral relationships. Module I was used to help the student pairs understand how to construct and manipulate with *Cabri*. Module II had the student pairs explore the rhombus, square, and kite. Finally, Module III had students explore six quadrilateral relationships: rhombus and square; rectangle and square; kite and rhombus; parallelogram and trapezoid; and rhombus, rectangle, and parallelogram. Upon completion of Module III, the student pairs created a hierarchical quadrilateral diagram with explanations for the location of each quadrilateral. By the completion of the modules, the pairs of students were using appropriate terminology for the geometrical objects within their discourse and assignments, were able to understand and appropriately use the features of *Cabri* to explore quadrilateral relationships, and were able to use knowledge gained from *Cabri to* accurately discuss unique relationships within and between quadrilaterals. As Jones summarized, “there was a shift in [student] thinking from imprecise, ‘everyday’ expressions, through reasoning mediated by the software environment to mathematical explanations of the geometric situation” (p. 80).

DGEs have also been shown to provide positive learning opportunities for diverse groups of students (Dixon, 1995; Myers, 2009). For example, Dixon (1995) found that utilization of *GSP* improved 8th grade ELL students’ understanding of geometric transformations. While five classes learned transformations through textbook-based direct instruction, students in the four experimental classes worked in pairs to complete *GSP*-based activities. ELL student pairs were allowed to converse in either English or their first language while completing the activities. Researcher-created end of unit assessments showed that a student’s level of English proficiency provided no significant interaction with achievement. More importantly, both English proficient and ELL students from the *GSP*-based classes performed significantly better on the posttest than their peers in the direct instruction classes. As Dixon summarized, “[This study] has shown that LEP [or ELL] students can learn to conjecture and test those conjectures in a Constructivist teaching and learning environment while simultaneously learning new mathematical vocabulary through context embedded situations” (p. 240).

DGEs are a unique digital tool that has been shown to also support learner-centered practices such as inquiry-based learning and student collaboration (Baharvand, 2001; Jones, 2000; Yousif, 1997). Additionally, students who are provided opportunities to use DGEs as a regular part of learning mathematics have shown significant improvement in reasoning and justification (Burkhead, 1998; Hollebrands, 2007; Jones, 2000; Marrades & Gutierrez, 2000). The use of DGEs has shown positive results in achievement for both researcher-created assessments and a state end-of-course exam as well (Baharvand, 2001; Dixon, 1995, Myers, 2009). Jones (2000) summarized:

> With carefully designed tasks, sensitive teacher input, and a classroom environment that encourages conjecturing and a focus on mathematical explanation, students can make progress with formulating mathematical explanations and coming to terms with inclusive definitions, both important aspects of developing a facility with deductive reasoning. (p. 81)

The 1:1 Classroom

In addition to integrating software like DGEs into the mathematics classroom, several states and districts have begun 1:1 classroom initiatives to improve the use of technology in all subject areas. In performing a meta-analysis of state executive reports for six major 1:1 laptop initiatives (*Florida Leveraging Laptops, Maine Learning Technology Initiative, Michigan Freedom to Learn, North Carolina 1:1 Learning Technology Initiative, Pennsylvania Classrooms for the Future, Texas Immersion Pilot,* and *Henrico County Teaching and Learning Initiative*), Argueta, Huff, Tingen, and Corn (in press) found that 1:1 laptop initiatives have had a significant positive influence on several student outcomes as well as teachers' instructional practices, especially when there was high implementation of laptop use. For example, student engagement increased when there was high implementation, but students often became distracted using laptops when implementation was low. Students' motivation to learn and interest in school increased with high implementation while students were indifferent or negative about the laptops where implementation was low. Additional studies found similar results in that when 1:1 initiatives were effectively implemented, students attended school more consistently, were more engaged in classes, completed more school work, and the quality of the school work improved (Lane, 2003; Silvernail & Lane, 2004; Warschauer, 2006;).

Research has been less consistent on student achievement in 1:1 initiatives. For instance, Dove (2011) used Multilevel modeling (MLM) to analyze the number of years a high school was 1:1 and the school's pass percents on the North Carolina Geometry end-of-course exam. In this study, data was collected on 12 1:1 high schools and 10 non-1:1 high schools that were demographically similar to the 1:1 schools. Data were collected from the 2006 to 2010 Geometry end-of-course exams. This included collecting data for the categories of school, gender, and economically disadvantaged students. With each category, data was collected for each group's pass percent, total number of students who passed, and total number of students who attempted the test. An additional category was created to signify how long a school had implemented their 1:1 initiative at the time of the exam, with the greatest length of time being three years. MLM analysis suggested that there was a positive significant relationship between the number of years a school was 1:1 and a school's EOC Geometry pass percent ($\gamma_{10} = 7.78$, $t = 5.74$, $p < .0001$) as well as between number of years a school was 1:1 and the EDS population's pass percent ($\gamma_{10} = 10.00$, $t = 5.42$, $p < .0001$). Further analysis suggested that the EDS population's pass percent mediated the relationship between the number of years a school was 1:1 and the school's pass percent ($z =$

5.27, $p < .0001$). This accounted for 84% of the within school variance in the total Geometry pass percent.

While additional studies have also found positive results in student achievement on exams across various core content areas (Muir, Knezek, and Christensen, 2004; Silvernail & Gritter, 2007; Shapley, Sheehan, Maloney, & Carnikas-Walker, 2010), others have shown no significant difference in achievement (Warschauer, 2006; Weston & Bain, 2010). From a meta-analysis, Argueta et al. (in press) suggested that student achievement was influenced by the level of implementation such that the state initiatives with high implementation had achievement score increases that were statistically significant while achievement scores for initiatives with low implementation showed no statistical difference or even decreased. For example, Mann (2008) found nonsignificant findings on most Virginia end-of-course exams in the *Henrico County Teaching and Learning Initiative*. However Mann recognized there was a significant amount of low implementation of laptop use within the imitative. To account for implementation, the data for the Geometry exam was aggregated by whether laptops were used at least once a week in the geometry class. Further analysis showed that in classes where this occurred, student achievement significantly increased on the Geometry end-of-course exam.

High implementation of laptop use in 1:1 initiatives has also been shown to improve students' and teachers' technology skills, critical thinking skills, communication and collaboration skills, and self-directed learning skills (Argueta et al., in press). For example, Corn (2009) found that teachers reported students in the *North Carolina 1:1 Learning Technology Initiative* showed increased skills in integrating digital tools such as blogs and wikis into their classroom projects. Teachers in higher-implementing schools also shifted their instructional practices to a more learner-centered approach, including more inquiry-based learning, project-based learning, student collaboration, more high-order questioning, and increased differentiated instruction (Argueta et al., in press; Cavanaugh et al., 2007; Corn, 2009; Fairman, 2004; Lowther et al., 2008).

Integrating Technology to Support Instructional Practices

How digital tools and resources are incorporated into teachers' instructional practices can potentially influence student engagement and achievement in the mathematics classroom. While technology can be used to provide teacher-centered instruction such as PowerPoint lectures, it can also be used to provide learner-centered activities like having students work with a partner to complete an exploratory activity using a DGE. Studies on DGEs as well as on 1:1 classroom initiatives have suggested that when the available technologies are used to support learner-centered instructional practices in comparison to teacher-centered practices, positive increases can occur in student achievement, motivation, and engagement (Baharvand, 2001; Cavanaugh et al., 2007; Corn, 2009; Dixon, 1995; Fairman, 2004; Mouza, 2008; Myers, 2009; Yousif, 1997).

However, research that has focused on integrating technology use into teachers' instructional practices has found mixed results (Becker, Ravitz, & Wong, 1999; Ruthven, Hennessy, & Deaney, 2008). In a national survey of teachers in the United States, Becker, Ravitz, & Wong (1999) found confounding results between mathematics teachers' perceptions of the most valuable mathematics programs for teaching and the programs that teachers actually utilized in their lessons. While mathematics teachers considered *GSP* the most valuable program in mathematics, they also noted that the programs most used within their classes were "very traditional skill-practice software" (p. 18).

Even studies that have examined teachers' integration of DGEs into lessons and activities have had mixed results. In a multiple method qualitative study that incorporated focus-group discussions, observations, and post-observation interviews, Ruthven et al. (2008) found that teachers used three different instructional practices with DGEs: full integration of learner-centered practices, partial use of learner-centered practices, and teacher-centered use of DGEs to perform demonstrations and presentations during direct instruction.

> Where dynamic geometry has entered mainstream classrooms, it appears to be used to support more established forms of pedagogical practice, notably student activity directed towards empirical confirmation of standard curricular results, often through guided discovery…[However] the degree to which students themselves were expected to make use of dynamic geometry was influenced by the extent to which this was seen as providing experience of a mathematical reference model for the topic in question, and more fundamentally as promoting mathematically disciplined interaction with a generalized geometric system. (p. 314)

One possible influence on how teachers use technology in their instructional practices may be the school environment created by the administration. In analyzing a statewide survey of Geometry teachers and principals, Coffland & Strickland (2004) found that of all the factors within the survey, the greatest correlation occurred between teachers' attitude and principals' attitude toward technology. Of the teacher respondents, 33 percent stated that the principal's expectations of technology use within the classroom was the main determining factor in how much technology was used to teach. While the use of technology does not specifically dictate the instructional methods, it does indicate the effect the administration of a school can have on whether teachers value incorporating technology into their lessons and activities.

Pressure from standardized testing also has the potential to influence how teachers integrate technology into their instructional practices (Hannafin et al., 2001; Ruthven et al., 2008). As part of a multi-method research program, Hannafin et al. (2001) observed the influence of transforming an 8th grade teacher's class using learner-centered instructional practices during the geometry unit. In this study, the teacher was to serve only as a facilitator and was not supposed to provide any direct instruction. In place of instruction, students worked in dyads to complete a booklet of 14 *GSP* activities that covered the geometry topics required in the eighth grade mathematics state standards. Observations suggested that the teacher struggled to relinquish control and instructional power to the students. Even though she recognized the excitement, motivation, and engagement of the students during the unit, as well as the success of the students on the end of unit assessment, the teacher still felt that the unit would have been better completed with the teacher leading direct instruction through the *GSP* activities. She also felt that she would have to review material before the state test as she observed weaknesses in certain areas of the material. However, "If it is true that students were more engaged [and more actively participating] than in their regular classroom, then opportunities for identifying an individual student's weaknesses and misconceptions are presumably more frequent" (p. 141).

Even with reservations on the use of learner-centered practices with technology-based activities, Pierce and Ball's (2009) survey of 92 Australian mathematics teachers found that over 75 percent of the teachers felt that using technology made teaching and learning mathematics more enjoyable, could improve student motivation and engagement, could help assist in discussing more complex mathematical ideas by building student discourse, and could be used to help incorporate real-world problems into the curriculum. This suggests that teachers may want to use more learner-centered instructional practices, but they may either feel the constraints of testing or have not been trained on how to effectively integrate such practices into their classroom instruction. For example, Hannafin et al. (2001) reflected that the observed teacher's struggles were possibly caused by her lack of familiarity with such instructional practices.

> Some of the teacher's discomfort with surrendering control was doubtless because she felt unprepared to facilitate and to scaffold instruction. We provided no formal training other than talking about strategies and describing our expectations. We simply asked her to assume the role of facilitator, reasoning that we would be there as me primary instructors to model some of the strategies. In hindsight, it is reasonable that she resorted to her more familiar behaviors as the implementation progressed (p. 141).

This collection of research suggests that teaching in technology-enhanced classrooms provides an opportunity to help teachers shift towards learner-centered instructional practices. However, this shift is not easy for teachers to make. The transition may become limited due to discomfort with the technology, lack of pedagogical understanding for incorporating the technology, or even apprehension of giving students control of their learning. The research suggests that there is more to teaching with such instructional practices in technology-enhanced learning environments than just providing teachers with digital tools and resources. As Corn (2009) stated from her findings in the evaluation report for the *North Carolina 1:1 Learning Technology Initiative*, "Teachers need additional professional development and support on creating a 1:1 classroom that employs advanced, interactive, digital instructional activities and strategies for differentiating instruction for students" (p. 5).

Professional Development that Supports Technology-Enhanced Instructional Practices

Professional development has the potential to influence changes in teaching in technology-enhanced learning environments. Providing appropriate professional development to influence such change in these environments is complex. To better understand what is needed for professional development to be effective and have an increased likelihood of influencing change in teachers' instructional practices, at least two national studies and a national meta-analysis of professional development studies have been conducted. In one national study, Darling-Hammond et al. (2009) analyzed the National Center for Education Statistics' 2003-2004 School and Staffing Survey which consisted of 130,000 teachers in 50 states as well as the NSDC's 2007-2008 Standards Assessment Inventory which included 150,000 teachers in 11 states and one Canadian province. "The purpose of this report [was] to provide policymakers, researchers, and school leaders with a teacher-development research base that can lead to powerful professional learning, instructional improvement, and student learning" (p. 4). In a second national study, Garet et al. (2001) analyzed the Eisenhower Professional Development Programs' 1998 Teacher Activity Survey from 1,027 teachers in 358 Eisenhower funded school districts. This study was designed to:

> Examine the relationship between features of professional development that have been identified in the literature and self-reported change in teachers' knowledge and skills and classroom teaching practices. [It then] integrated and operationalized the ideas in the literature on "best practices" in professional development to create a set of scales describing the characteristics of activities assisted by the Eisenhower program, then empirically tested these characteristics to examine their effects on teacher outcomes. (p. 918)

Finally, in an Institute of Education Sciences report for the National Center for Education Evaluation and Regional Assistance, Yoon et al. (2007) began by examining over 1,300 professional development studies, but performed a meta-analysis on only nine studies they deemed rigorous by What Works Clearinghouse's standards. The purpose of this meta-analysis was to determine how professional development could influence student achievement. These three studies concluded that effective professional development required four fundamental components: significant time spent in the professional development, including number of hours and total length; content-specific topics; use of learner-centered instructional practices to teach the professional development events; and coherence of the activities within the professional development as a whole (Darling-Hammond et al.,2009; Garet et al., 2001; Yoon et al., 2007).

The first aspect of successful professional development is the amount of time it utilizes, including both the amount of hours and the total duration. Opportunities that have shown significant improvement in teaching and student achievement typically account for at least 30 hours of training and span a minimum of six months (Darling-Hammond et al., 2009; Garet et al., 2001; Penuel et al., 2007; Yoon et al., 2007). Yoon et al. (2007) found in their meta-analysis that teachers who received at least 49 hours of professional development had their student achievement scores increase by 21 percentile points. Additionally, Garet et al. (2001) found that increased contact hours also increased the occurrence of the other three components needed for successful professional development within the given professional development. Unfortunately, shorter events that last 16 hours or less, such as one to two day workshops that do not include follow-up, have shown no significant effect on improving student achievement (Yoon et al., 2007). Darling-Hammond et al. (2009) found that the professional development opportunities for over 90% of their respondents consisted primarily of such events that were less than 16 hours over a two-day period. Garet et al. (2001) found similar results, such that only professional development opportunities that met the time expectations of 30 hours and six months positively influenced teachers' knowledge or instructional practices. Providing teachers extensive and sustained professional development opportunities is the first important aspect needed so that teachers will have enough opportunities to learn how to effectively teach using learner-centered instructional practices in a technology intensive environment.

As the second component, the content of the professional development is equally important to duration of the opportunities. Garet et al. (2001) stated that there are four elements for how content can be directed within professional development. It can be used for: providing a specific method to teach specific content; improving overall content knowledge; improving overall general pedagogical practices; or improving overall pedagogical content knowledge (PCK). The emphasis of the professional development will then influence the degree to which the activities focus on learner-centered practices. Of these four elements, professional development that focused around PCK had a greater significant influence on improving learner-centered instructional practices due to the ability to incorporate important pedagogical practices around specific content, thus making the activities more relevant to the teachers (Darling-Hammond et al., 2009; Garet et al., 2001; Yoon et al., 2007). However, professional development must also find ways to integrate technology into the PCK (Harris, Mishra, & Koehler, 2007; Mishra & Koehler, 2006). Ferrini-Mundy and Breaux (2008) stated, "In the absence of professional development on instructional technology and curriculum materials that integrate technology use into the lesson content, teachers are not particularly likely to embed technology-based or technology-rich activities into their courses" (pp. 437- 438).

The third important aspect for successful professional development focuses on the method of instruction of the event. Professional development should focus on providing teachers opportunities for active learning, which can include: (a) observing experienced teachers or being observed to discuss teaching methods; (b) group planning of curricula based around concepts learned from professional development experiences; and (c) working in groups during an event to discuss and review student work, especially around concepts that are likely to provide the greatest difficulty for students to learn (Garet et al., 2001).

Studies have suggested that these methods lead to increased teacher engagement during the professional development, increased positive attitudes and beliefs around the objectives of the professional development, and increased knowledge on how to use learner-centered instructional practices within their individual classrooms (Darling-Hammond et al., 2009; Garet et al., 2001; Klieger et al., 2009; Penuel et al., 2007).

The final element incorporated in successful professional development is a coherence of activities throughout the entire experience. Aspects of coherence include: connections to teaching goals and other activities in the overall professional development; alignment with district, state, and national standards and assessments; and types of communication with the instructors and other participants both during and after the event (Darling-Hammond et al., 2009; Garet et al., 2001). Garet et al. (2001) found that coherence had significant positive effects on increasing teachers' PCK. The researchers also found that coherence was a significant positive predictor for determining whether teachers began to change their instructional practices to include more learner-centered practices that they learned from their professional development experiences. However, Darling-Hammond et al. (2009) found coherence was practically nonexistent within much of the surveyed teachers' professional development. Garet et al. (2001) found that a considerable portion of the Eisenhower Professional Development Program activities also lacked coherence.

The four components of time, content, participant-centered instructional practices, and program coherence provide a foundation for professional development to successfully improve teachers' learner-centered instructional practices (Darling-Hammond et al., 2009; Garet et al., 2001; Yoon et al., 2007). However, these components are not independent of one another. The absence of one can impact the others and potentially limit the success of the entire professional development experience. This is especially true for professional development that focuses on how to effectively incorporate learner-centered instructional practices in a technology-enhanced learning environment. Harris, Mishra, & Koehler (2007) suggested there are currently several common attempts at technology-based professional development: a focus on software without content connection, demonstrations of technology without individual participation, structured workshops, and technology-focused teacher education. These methods were noted to be weak and flawed because "these approaches tend to initiate and organize their efforts according to the educational technologies being used, rather than students' learning needs relative to curriculum-based content standards" (p. 3). Such professional development runs counter to the four components of effective professional development, especially around the amount of time and the engagement of the participants (Darling-Hammond et al., 2009; Garet et al., 2001). With relation to professional development for incorporating technology into teachers' instructional practices:

> Technology integration approaches that do not reflect disciplinary knowledge differences, and the corresponding processes for developing such knowledge, ultimately are of limited utility and significance, ignoring as they do the full complexity of the dynamic realities of teaching effectively with technology. (Harris, Mishra, & Koehler, 2007, p. 4)

To better utilize the four foundational components of professional development while incorporating technology, Koehler and Mishra (2005) developed the Learning by Design approach. This experience is deeply immersed in technology-enhanced participant-centered practices for which teachers work collaboratively in groups to create solutions with technology around subject-specific pedagogical issues in teaching. With this approach:

> Teachers focus on a problem of practice, and seek ways to use technology (and thereby learn about technology) to address the problem. Because their explorations of technology are tied to their attempts to solve educational problems, teachers learn "how to learn" about technology and "how to think" about technology. Hence, teachers go beyond thinking of themselves as being passive *users* of technological tools and begin thinking of themselves as being *designers* of technology (p. 95).

This in turn requires participants to collaborate, communicate, and find ways to efficiently work together to solve complex situations. Because of the learner-centered approach, Learning by Design is also a very coherent method of professional development that continually makes connections between activities. As prior research has suggested (Darling-Hammond et al., 2009; Garet et al., 2001; Penuel et al., 2007), this coherence is a significant aspect that helps teachers make the connections between practice and theory, thus allowing them to understand why and how to effectively utilize learner-centered instructional practices into their technology-enhanced classrooms (Mishra & Koehler, 2006; Koehler & Mishra, 2005).

Summary

Current literature has suggested that learner-centered instructional practices and the integration of technology into these practices can support student engagement and learning. However, effective use of technology often requires teachers to utilize learner-centered instructional practices with novel problems and active classroom discourse. The integration of technology creates an additional layer of complexity to utilizing such practices. While integrating learner-centered instructional practices into technology-enhanced classrooms may be a difficult undertaking, it is one that will be necessary. As the amount of technology increases in society, it will be more imperative to have teachers that can find ways to utilize technology within the classroom that keep students engaged and motivated in learning. Teachers will need to assist students in developing deeper understandings of the content that they are studying, which is essential in many career opportunities of the 21st century. Professional development grounded in research will likely be necessary to help teachers meet these needs.

The current literature also provides areas for continued research. For instance, while research has been conducted on the use of various technologies in the mathematics classroom, there is little research on teaching and learning in the 1:1 mathematics classroom. The literature has also suggested that digital tools and resources cannot simply be given to teachers, but professional development is needed to help with their integration into teachers' instructional practices. For that reason, additional research is needed to better understand what specific components of professional development may be necessary for mathematics teachers to integrate available technologies into learner-centered instructional practices. This is especially needed for 1:1 mathematics teachers as they are expected to regularly incorporate computer-based student activities into their lessons. Finally, as teachers receive professional development, research will be needed to explore if and how integration of technology and instructional practices changes as mathematics teachers participate in these new professional development opportunities. The current study explored this final area of future research. By examining teachers' instructional practices and technology integration while participating in long-term professional development, this study hoped to provide new insight into the complexities of teaching in 1:1 mathematics classrooms.

CHAPTER 3

Methodology

Overall approach and rationale

This study utilized a collective case study design (Creswell, 2007) and focused on five Geometry teachers in the same school district. All of these teachers are participating in long-term professional development on teaching Geometry with *GSP* in a 1:1 classroom environment. The unit of analysis for this study was the individual teacher. The individual teacher was chosen for several reasons. First, while all five teachers participated in the same professional development, each teacher had his or her own unique experiences. Additionally, while the teachers worked in the same county, they taught at three different schools that included different demographics, administrations, and school cultures. Data was triangulated using methods of observations, interviews, and teaching artifacts.

Case Study.

Creswell (2007) stated that there are five primary approaches to qualitative research: narrative/interpretive: phenomenology, grounded theory, ethnography, and case study. The approach of case study and cross-case analysis was chosen for this study as it provided the greatest opportunity for understanding how specific long-term professional development may influence individual teachers during the first six months of their participation. As stated by Creswell, "Case study research involves the study of an issue explored through one or more cases within a bounded system" (p. 73). For this study, the bounded system (or contextual setting) was a single rural school district in North Carolina in which the high schools were implementing 1:1 classroom initiatives. While the teachers were at the three different high schools within the district, all participated in the same professional development. The case study method allowed for an opportunity to study teachers' instructional practices and their use of technology. Case study allowed for various methods of data collection, which were used to triangulate findings. The analysis of each case was then used to build themes and patterns, which were explored to describe change throughout the semester both individually and collectively.

Framework of Study.

The framework of this study was adapted from the Levels of Technology Innovation framework (LoTi) (Moersch, 2002) (Table 1). LoTi was first created in 1994 as a conceptual framework to "assist school districts in restructuring their staff's curricula to include concept/process-based instruction, authentic uses of technology, and qualitative assessment" (Moersch, 1995, p. 41). Work from the Concerns-Based Adoption Model (CBAM) (Hall & Hord, 1987) and Apple's Classrooms of Tomorrow (ACOT, 1995) was considered as LoTi was developed. In LoTi the "primary emphasis is given to the degree that technology is used to support a constructivist orientation to classroom pedagogy based on the available hardware and software at the school site" (Moersch, 1996, pp. 52 – 53). This emphasis led to the creation of a framework with eight levels: Nonuse, Awareness, Exploration, Infusion, Integration (Mechanical), Integration (Routine), Expansion, and Refinement (Moersch, 2002). Each level identifies if technology is integrated, the role of the teacher and the student in using the technology, the type of tasks that incorporate technology, and the cognitive demand of these tasks (Table 1).

A major shift in technology integration and instructional practices can be observed within this framework. Moersch (2002) stated about LoTi:

> As one progresses from one level to the next, a corresponding series of changes to instructional curriculum are observed. The instructional focus shifts from a teacher-centered to a learner-centered orientation. The computer technology is employed as a tool to support and extend students' understanding of pertinent concepts, processes, and themes… Traditional verbal and paper-and-pencil activities are gradually replaced by authentic hands-on inquiry related to a problem, issue, or theme… Sequential materials are replaced by extensive and diversified resources that are determined by the problem areas under study. Traditional evaluation practices are supplanted by multiple assessment strategies. (p. 49)

Since the formation of the framework, multiple surveys and protocols have been created that integrate LoTi. This has included questionnaires to examine LoTi levels of teachers and administrators, strategies for collecting data to examine LoTi levels, and observation protocols to determine teachers' LoTi levels for a lesson. These materials are currently used in school districts in over 20 states and have been implemented as research instruments for over 60 dissertations.

Table 1: Levels of Technology Innovation (LoTi) (LoTi Connection Inc., 2010)

Level	Characteristics of the Level
Level 0: Nonuse	• Instructional focus can range from teacher-centered or student-centered • Digital tools and resources are not used
Level 1: Awareness	• Instructional focus is teacher-centered with emphasis on direction instruction • Teacher questioning and/or student learning typically focuses on lower-level thinking • Teacher uses digital tools and resources to enhance teacher-directed lessons or as a reward for completing work in class
Level 2: Exploration	• Instructional focus is teacher-centered with emphasis on content understanding and mastery learning • Teacher questioning and/or student learning typically focuses on lower-level thinking • Students use digital tools and resources for extension, enrichment, information gathering activities that typically are of low demand
Level 3: Infusion	• Instructional focus is student-centered with emphasis on applied learning and problem-based models • Teacher relies on outside materials, resources, and/or interventions to engage student problem solving • Content-related higher-order thinking by students • Students use technology to answer teacher-generated, high cognitive demand questions
Level 4a: Integration (Mechanical)	• Instructional focus is student-centered with emphasis on learner-centered strategies • Teacher is comfortable promoting inquiry-based modeling • Content-related higher-order thinking by students and real-world application of the content are evident • Students use technology to answer student-generated questions and other real-world problems

Table 1 Continued

Level 4a: Integration (Routine)	• Instructional focus is student-centered with emphasis on learner-centered strategies • Teacher is comfortable promoting inquiry-based modeling • Content-related higher-order thinking by students and real-world application of the content are evident • Students use technology to answer student-generated questions and other real-world problems
Level 5: Expansion	• Instructional focus is student-centered with emphasis on learner-centered strategies and collaboration with groups outside of school • Students use complex thinking skills and collaborative expertise from the community to solve relevant problems • Students use multiple technologies for personally-relevant, high demand, authentic tasks
Level 6: Refinement	• Instructional focus is student-centered with emphasis on learner-centered strategies and collaboration with groups outside of school • Curriculum is learner-based and emerges on needs of the learner • Students use complex thinking skills and collaborative expertise from the community to solve relevant problems • Students use unlimited access to multiple technologies as a tool to master any student-driven learning experience (e.g., content, process, and product).

Premise of Study.

The participants selected for the study are participating in a larger multi-year project, *Scaling Up STEM Learning with the VCL (Scaling Up)*, which is sponsored by the ITEST program of the NSF. There are three components to *Scaling Up*: (1) Delivering mathematics-specific software via the VCL; (2) On-going sustained professional development to prepare teachers to use this software with their students in high school mathematics classrooms; and (3) A mentor network to connect students with STEM professionals to increase student interest in mathematics. *Scaling Up* is working with four counties in North Carolina that have 1:1 laptop initiatives. The project deployed a virtual computing laboratory (VCL) to provide *GSP* in one of the four counties. The VCL is a cloud computing network that can be accessed anywhere worldwide. The VCL serves as a remote access service that allows teachers to reserve software applications for their entire class to use without actually having the software installed on each computer. The VCL includes the Key Curriculum Press core software of *The Geometer's Sketchpad* (*GSP*) Version 5 (Jackiw, 2010), *Tinkerplots* Version 1.0 (Konold & Miller, 2005), and *Fathom* Version 2.0 (Finzer, 2005). The other three counties, including the one from which the study's participants taught, had the Key Curriculum Press software physically loaded on every computer in the school.

In the first phase of *Scaling Up,* Geometry teachers in the four counties are being provided two years of long-term professional development. During the first year, the professional development included a five-day Summer Institute and six monthly five to eight hour online professional development modules during the school year that incorporated how to effectively integrate content, pedagogy, and technology while teaching Geometry with *GSP*. Similar professional development will be provided during the second year of *Scaling Up*.

Professional Development Events.

Summer Institute.

Throughout *Scaling Up,* the Geometry teachers of these four counties participated in several professional development opportunities. First, in the 2010 summer there was a week-long face-to-face Summer Institute. This was held at a large university and was led by a principal investigator of *Scaling Up,* a doctoral graduate research assistant of *Scaling Up,* and the researcher of this study. The purpose of the institute was to increase technology knowledge and overall use of *GSP*, content knowledge in geometry, and knowledge about how to effectively incorporate *GSP* into teaching geometry. Since the teachers are participating in two years of professional development, the Summer Institute focused on topics that would provide a foundation for the use of *GSP* and other technologies in the Geometry classroom (Appendix A). With each topic, the teachers had to use their content knowledge to critically explore activities through *GSP*. They would then discuss how *GSP* may be incorporated into their individual classes, what opportunities and challenges this may provide, and how challenges may be addressed and overcome without removing the technology. Additionally, teachers created a lesson plan with a partner that incorporated at least one *GSP* activity. These lessons were shared the final day as a way of demonstrating the technological and pedagogical knowledge they had learned during the Summer Institute.

Online Professional Development.

During the school year, the teachers completed a six-unit online professional development course (Appendix B). This professional development was created by Key Curriculum Press, the creators of *GSP*, but was facilitated by a member of the *Scaling Up* staff. The online course materials were designed to help increase teachers' content knowledge in Geometry, teachers' technology knowledge in using *GSP*, and teachers' pedagogical knowledge on leveraging *GSP* to teach Geometry. This course is offered by Key Curriculum Press as a six-week course. However, permission was given for *Scaling Up* to turn each weekly module into a monthly module. *Scaling Up* chose to use monthly modules for two reasons. First, offering one module a month placed less stress on teachers as they were working to create new lessons to integrate *GSP* into their classes. Second, by spreading the modules to once a month, teachers were continually using *GSP* throughout the entire year. This was important to the staff of *Scaling Up* as many of the teachers only taught geometry one semester during the year. This staff also hoped that this would help maintain and reinforce technical and pedagogical skills for using *GSP* throughout the entire year.

Teachers completed each module individually and asynchronously throughout each month. They were required to submit various activities and participate in the module's discussion forums by the end of each month. Each forum included pre-determined prompts that asked participants to reflect either on completing the module or on a teaching moment with *GSP*. Several forums also included teacher-initiated and participant-initiated discussion threads. The discussion forums were intended to build an online community where teacher's who were experiencing similar issues in using *GSP* could share their thoughts, concerns, experiences, and ideas. Each module took approximately five to eight hours to complete.

Participant Selection

The five participants for the study were Geometry teachers from the same county that are participating in *Scaling Up*. This county was purposefully chosen because it provided the greatest number of teachers that taught Geometry during the 2010 fall semester. Using participants from the same county was desirable for this study as it was anticipated that their teaching situations would be more similar than choosing participants from multiple counties, thus allowing for better cross-case analysis. While five teachers participated in the study, only four were analyzed due to data collection issues with the fifth teacher (Table 2).

Table 2: Participants of the Study

Teacher	School	Years Teaching	Class Observed
Reese	School A	5	Honors Geometry
Rob	School B	3	Standard Geometry
Sarah	School C	22	Honors Geometry
Sean	School B	12	Standard Geometry

Within the county were three high schools, which will be referred to as school A, school B, and school C. Demographics for each school can be found in Table 3. The county 1:1 laptop initiative was initiated through various grants over several years. While the county had been using a cart-based laptop program, school A received additional Golden Leaf funds during the 2008-2009 school year to implement a 24/7 1:1 laptop initiative. The county then redistributed the laptop carts from school A to school B and school C and purchased new laptops for teachers across the county so that all three schools could begin the 1:1 laptop initiative at the same time. The district officially implemented the 24/7 1:1 initiative during the 2009-2010 school year. As the lease expired on all the laptop carts that had been distributed in school B and school C, students in both schools received new Mac Book Pros with the beginning of the 2010-2011 school year.

Table 3: School Demographic Information

School	Total Population	Percent Male	Percent Female	Percent Caucasian	Percent African American	Percent Hispanic	Percent Other Minorities
A	741	54	46	36	18	42	4
B	977	52	48	71	17	9	3
C	457	54	46	79	12	7	2

Coming into the study, each teacher had varied use of the laptops in their classroom. Additionally, they varied in their use of *GSP* prior to the 2010 Summer Institute. The variation among teachers benefitted this multiple case study as it allowed for observation of how the professional development opportunities influenced instructional practices and integration of technology among teachers with different backgrounds. Using teachers from the same school district included several advantages for this study as the teachers were teaching in similar contexts. Teachers had the same laptops, the same programs available, the same online textbook, and participated in the same professional development experiences during the study. Having similar contextual settings provided the opportunity for analysis both within cases and between cases to examine instructional practices and integration of technology for each teacher and what commonalities and differences may have occurred between the four teachers.

Data gathering methods

Multiple qualitative methods were used to gather data within this study. These methods provided various forms of data which were used to complete a thorough analysis of each case (Meadows and Morse, 2001). Multiple data sources within this study included observations, interviews, emails, and lesson artifacts such as activity worksheets, *GSP* files, and the teacher's website. Use of multiple methods helped provide validation of characterizations as the multiple data sources aided in triangulation of the findings by the researcher within each case (Silverman, 2006).

Observations.

All three high schools used semester-based classes. Semester-based class, or 4x4 block scheduling, is similar to standard college semesters in that students take four classes each semester. Each class met every day for approximately 90 minutes. Each teacher was observed approximately once each month during the fall semester for a total of four observations. Four observations were chosen to at least follow the teachers through each month of the semester while also not disturbing the classroom environment created by the teacher. During these observations, the researcher sat in a location designated by the teacher so that the researcher caused the least amount of disruption for the teacher's students. While each lesson occurred, the researcher took field notes on his computer in a Word document (Appendix C; Appendix D). The notes included a description of the activities that occurred, questions posed by the teacher, perceived engagement of the students, and other pertinent information that may provide evidence to the teacher's instructional practices or technology integration during the given observation. Perceived student engagement included whether students were active or passive during a classroom activity, if work was completed individually or in groups, whether students appeared on-task, and whether students' discourse was on-task. Each observation occurred for the entire duration of the class.

Lesson Artifacts.

During each observation, the teacher was asked to provide any materials that may have been relevant to the given lesson. Borko et al. (2007) suggested, "When used judiciously as part of a data collection system, [artifact analysis] can offer valuable information about many aspects of reform-oriented practice" (p. 69). The materials varied by teacher and by lesson. For example, teachers provided textbook-based activity worksheets, individually-created worksheets, PDF documents of worksheets, *GSP* files, and quizzes. When materials were not readily available, the teachers would email copies or refer the researcher to his/her website for the given documents. These documents were marked according to their location within a lesson to aid in analysis of each observation.

Interviews.

Post-observation interviews occurred at a time convenient for the teacher. This ranged from face-to-face interviews directly after the observed lesson to phone interviews during the teacher's lesson planning period one to two days afterward. The interview was semi-structured and audio recorded. It included 11 questions for the first three interviews (Appendix E) and 16 during the final interview (Appendix F). Follow-up questions were asked for teachers to elaborate on some their responses.

Questions were posed to probe how the teacher created the lesson, how they perceived the lesson went, whether the lesson went as planned, why or why not specific technology was used, challenges addressed during the lesson, and possible alterations to the lesson for future use. Also the teacher was asked about any specific event that occurred during the lesson that the researcher found interesting. Because some of the teachers were new to incorporating *GSP* in their instruction, it was considered possible that they may have concerns related to personal use of *GSP* and/or upcoming lessons in which they were using *GSP*. For this reason, each interview concluded with an opportunity for the teacher to ask the researcher for assistance with these concerns or any other pertinent topics he/she wished to discuss. This allowed the teacher to share issues that may not have been addressed with the interview questions while also helping him/her improve his/her pedagogical practices with the use of technology.

Beyond the interviews, the researcher allowed the teachers to contact him between observations to receive any additional help they may have needed in upcoming lesson planning. This contact took place via email. The emails were saved with all other data collected for this study.

The ability to contact the researcher for assistance was provided for several reasons. First, the researcher had been involved in facilitating both the Summer Institute and the fall modules of the online professional development. Participants recognized him as a trusted resource as they continued to incorporate *GSP* into their lessons. At the same time, these conversations allowed the researcher to better characterize the teacher's integration of technology and how it was changing throughout the course of the study.

Data analysis procedures

Analysis was completed at several levels following methods suggested by Creswell (2007). Creswell stated:

> When multiple cases are chosen, a typical format is to first provide a detailed description of each case and themes within the case, called a *within-case analysis*,

> followed by a thematic analysis across the cases, called a *cross-case analysis*, as well as *assertions* or an interpretation of the meaning of the case. (p. 75)

First, a detailed description of each case was created. To provide adequate understanding of each teacher, each observation's field notes and lesson artifacts was analyzed using LoTi. For this study, LoTi was divided into its two components: technology integration and instructional practices (Table 2). This division was made as it was anticipated that teachers might implement lessons that did not integrate technology. However, it was important to understand the instructional practices that were utilized even when technology was not used. This allowed for examination of how technology was being integrated, how teachers' instructional practices may shift due to technology integration, whether these shifts influenced the cognitive demand of the activities, and whether these shifts influenced student discourse and engagement within the class. The analyses were then combined and reviewed for each teacher to provide a chronology of instructional practices and integration of technology over the course of the semester.

Next, each case was examined to search for emerging trends and themes from the data, "not for generalizing beyond the case, but for understanding the complexity of the case" (p. 75). Finally, cross-analysis occurred to examine commonalities and differences between teachers in their instructional practices, technology integration, and their perceived influence of the professional development.

Observation Analysis.

Analysis of the observations first began at the level of each individual. Each observation included both the researcher's field notes and the lesson artifacts. Each lesson was coded using two categories adapted from the LoTi framework (Moersch, 2002): Level of Technology Integration, and Level of Instructional Practices (Table 4).

Table 4: Modified LoTi Framework for Coding Each Observation

Level	Technology Integration	Instructional Practices
0	Digital tools and resources are not used	• Not applicable
1	Teacher uses digital tools and resources to enhance teacher-directed lessons or as a reward for completing work in class	• Instructional focus is teacher-centered with emphasis on direction instruction • Teacher questioning and/or student learning typically focuses on lower-level thinking • There is no evidence of student discourse
2	Students use digital tools and resources for extension, enrichment, information gathering activities that typically are of low demand	• Instructional focus is teacher-centered with emphasis on content understanding and mastery learning • Teacher questioning and/or student learning typically focuses on lower-level thinking • There is little evidence of student discourse
3	Students use digital tools and resources for teacher-created, high demand tasks	• Instructional focus is teacher-centered with emphasis on engaged learning with high demand tasks • Teacher includes strategies such as concept attainment, inductive thinking, and scientific inquiry with available digital tools and resources • Content-related higher-order thinking by students is clearly evident, but no real-world connection is made • Student discourse is clearly evident

Table 4 Continued

4a	Students use technology to answer student-generated questions and other real-world problems	• Instructional focus is student-centered with emphasis on applied learning and problem-based models • Teacher relies on outside materials, resources, and/or interventions to engage student problem solving • Content-related higher-order thinking by students and real-world application of the content are evident • Student discourse is clearly evident
4b	Students use technology to answer student-generated questions and other real-world problems	• Instructional focus is student-centered with emphasis on learner-centered strategies • Teacher is comfortable promoting inquiry-based modeling • Content-related higher-order thinking by students and real-world application of the content are evident • Student discourse is clearly evident
5	Students use multiple technologies for personally-relevant, high demand, authentic tasks	• Instructional focus is student-centered with emphasis on learner-centered strategies and collaboration with groups outside of school • Students use complex thinking skills and collaborative expertise from the community to solve relevant problems
6	Students use unlimited access to multiple technologies as a tool to master any student-driven learning experience (e.g., content, process, and product).	• Instructional focus is student-centered with emphasis on learner-centered strategies and collaboration with groups outside of school • Curriculum is learner-based and emerges on needs of the learner • Students use complex thinking skills and collaborative expertise from the community to solve relevant problems

Each observation was analyzed based upon events that occurred during the lesson. For example, many observations began with review, was followed by an exploratory activity, and concluded with practice or homework. Each of these events was examined to determine if technology-based tools had been integrated. If so, each section or activity of the lesson that did incorporate technology-based tools, including the artifacts used during that activity, was further examined to understand how technology was used. This included determining whether it was used primarily by the teacher to enhance direct instruction or whether it was utilized primarily by the students. If technology was used by the students, it was examined as to whether they used it for low demand or high demand activities as well as whether or not these activities were based in real-world problem. The cognitive demand level of each activity was examined using the Stein and Smith's (1998) framework with memorization and procedures without connections being considered low cognitive demand activities and procedures with connections and doing mathematics being considered high cognitive demand activities.

As student discourse was part of the LoTi levels, it was also examined for each lesson. Primary analysis included determining whether students were allowed to work with each other, how they participated in class discussion, and whether they were asked to provide conjectures, solutions, justifications, and explanations in small group and class discussions. This also included observing how many students could be characterized as on-task or off-task either by overheard discussions or by what appeared on their computer screen. For example, high student discourse occurred when students were provided opportunities to collaborate in activities, participated in whole class discussions, and/or were generally expected to provide evidence towards their solutions or conjectures.

As a coding example, suppose a teacher created a *GSP* activity in which students were to find the optimal location of a new movie theater that serves three small towns, and wherever roads do not exist, they will have to be constructed to help citizens get to the theater. If the teacher created this activity, allowed students to work together, provided students an opportunity to share their solutions, and discussed how these optimal locations relate to points of concurrency in a triangle, the teacher would be categorized as level 4b for Technology Integration and Instructional Practices. If the teacher did all of this, but he/she got the activity and guiding questions from a book or another teacher, he/she would be characterized as level 4a for both categories. Implementation of the activity could also have the teacher be categorized as level 2. For instance, the teacher could begin with the activity, but tell students to create the three points of concurrency, see which point cost the least to construct new roads, and submit their work. This would be level 2 because the teacher would have removed the cognitive demand of determining that points of concurrency would be relevant, that there is more to planning than the cost of the road that could be justified, and students would not have had opportunities for discourse.

Once coding for each lesson was completed, each teacher’s set of observations were analyzed collectively to see if their integration of technology and instructional practices shifted throughout the semester. Finally, a cross-analysis of the four teachers was conducted to identify similarities and differences in technology integration and instructional practices.

Interview Analysis.

Coding of the interviews occurred after observation analysis and followed a similar pattern as the observation coding. Analysis was completed around the teacher's perceptions of his/her technology integration and instructional practices. Additionally, interviews were examined for the teachers' reflections on perceived changes in their planning and teaching.

The analyses from these interviews were incorporated into the observation analysis to provide multiple perspectives of each activity, lesson, and case. Use of the interviews also provided comparison for how teacher thought about technology integration and the instructional practices that accompany technology integration. Finally, the interviews provided an opportunity to examine whether there were changes in these perceptions throughout the course of the semester.

Individual Case Creation.

Upon completion of analysis of the four observations, the artifacts for the observations, and the post-observation interviews, each case was formed. The cases were examined at each observation point. For each observation, the analyses were used to determine the most appropriate LoTi level characterization for Technology Integration and Instructional Practices. Data from the field notes and interviews were integrated to support each characterization. A summary was then created to examine each participant's potential changes throughout semester as well as factors that may have enhanced or limited such changes. Finally, interview analyses were used to provide the participants view on if and/or how the on-going professional development influenced their teaching and lesson planning throughout the semester.

Cross-Case Analysis.

The cross-case analysis followed the suggestions of Yin (2003) who stated that for cross-case analysis, one must first identify issues within the individual cases and then examine these issues to identify themes that emerge from multiple participants. To complete this task, the results of each case were created first. As each case was created, the researcher noted any topics that continued to arise or were considered possibly cross-cutting with other participants (Table 5).

Table 5: Individual Topics Examined for Common Themes

Rob	• Positive influence of professional development • Opportunities to work with colleagues • Time for completing activities • Continuing to learn *GSP* (topic limitations; unrealized limitations; creating appropriate tasks) • Shift in beliefs and use of student collaboration • Increases in levels Instructional Practices and Technology Integration • Increased use of *GSP*
Reese	• Issues with classroom management • Issues with student engagement • Concern with limitations of *GSP* • Increased use of *GSP* • Continuing to learn *GSP* (topic limitations; creating appropriate tasks; providing appropriate directions) • Use of professional development materials • Issue with time to complete curricilum
Sarah	• Concern with students talking/discourse • Increased use of *GSP*, primarily with high demand tasks • Continuing to learn *GSP* (topic limitations; providing appropriate directions) • Positive influence of professional development • Learning time for activities • Issue with time to get complete curriculum

Table 5 Continued

Sean	• Continuous use of *GSP* in high demand tasks • Concern with building student confidence • Students projecting work • Encouraging discourse in *GSP* activities through partners and whole group sharing • Collaboration with colleagues • Creation of online *GSP* activity repository • Continuous reflection on length of activities and examining overall curriculum

Several topics directly appeared in at least two cases such as colleague collaboration, student discourse, use of *GSP* (both success and struggles), and support for professional development. The other topics were closely examined to determine what may be combined to create a theme and what may have been primarily an issue for one teacher. For example, problems with classroom management occurred primarily in Reese's class, thus it was discarded as a theme for this analysis. In contrast, the topic of timing arose in several different ways, such as providing adequate time for students to complete activities and recognizing constraints of time to complete the curriculum. These were combined into a common theme of time. Finally, several ideas around formation of *GSP* activities were broadened to examine the scaffolding of these activities and how that led to potential success or struggles.

With six tentative themes, each case was analyzed to find supporting data for the theme. Afterward, each interview was re-analyzed to provide additional support through direct quotes that may not have been used within the creation of each case. However, if a theme emerged from the interviews that was not initially recognized within the case analysis, the entire case was again examined to see how the theme potentially influenced the teacher's instructional practices and integration of technology at each observation and across the semester. For example, if a teacher suggested in an interview that he/she was struggling with completing *GSP* activities in the time allotted, each observation would be re-examined to see how the teacher may or may not have altered an activity or lesson and whether this issue was limited to a specific observation or may have been more prevalent during semester than initially thought.

From the analysis, two additional concepts arose. First, the themes often related to either challenges or supports that influenced how teachers integrated technology into their lessons and what instructional practices they used. This led to each theme being labeled either a challenge or a support. Second, the theme for the use of *GSP* was recognized as too broad under this labeling system because it was observed as both a challenge and a support for teachers. For that reason, it was divided into two individual themes, one that examined the use of *GSP* as a support and the other that analyzed it as a challenge.

From the division of the use of *GSP* and the creation of supports and challenges emerged four common challenges and three common supports among the teachers. The challenges included general issues of time, learning *GSP* and its limitations, determining appropriate scaffolding for activities, and handling student discourse. The supports included success in implementation of *GSP* activities, on-going professional development, and creation of a colleague support system.

Ethical Issues and Potential Risks

The Internal Review Board at North Carolina State University approved this study (IRB# 1219) for exemption (Appendix G). All participants had the right to take part in this study or decline at any time (Appendix H). The potential risks involved with this study were minimal. To ensure participant confidentiality, schools and teachers were given pseudonyms. Classroom disruption due to observation was minimized by setting up times that were convenient for the teacher and by sitting in a location that the teacher felt most appropriate.

Several measures were also taken to ensure the safety of all data collected. First, the online workshop was located at a secure online location that only participants of the *Scaling Up* project and facilitators could access. All files (field notes, observation artifacts, data from the professional development, and digital interview recordings) were stored in a single folder on a password protected computer. This folder was backed up on a hard-drive as a precautionary measure. All recordings were destroyed from any used recorders once the files were transferred to the computer folder.

CHAPTER 4

Individual Cases

Following the completion of the observations, each teacher's field notes, lesson artifacts, and interviews were analyzed using the modified LoTi framework with each observation being characterized for the teacher's level of technology integration and level of instructional practices. The following discussion presents each teacher's observation, characterizations, and a summary of their changes throughout the course of the semester.

Case 1: Rob

Rob was a case of a new teacher who was learning how to integrate technology into his lessons. During the observed semester, Rob was beginning his third year teaching and his third year teaching Geometry. Rob received his teaching license through his undergraduate program at a large Midwestern university. This license reciprocated once he moved, thus providing him full licensure to teach secondary mathematics in North Carolina. All observations took place during Rob's second period standard Geometry class. The class averaged 22 students during observations. There were approximately 14 male and 8 female students.

The arrangement of Rob's classroom remained the same during all observations. Desks were set in rows facing the front. The front wall consisted of three white boards. At the front left of the room was a document camera and Rob's laptop. Both were connected to a mobile projector that projected to the front left whiteboard. Posters were displayed on the wall that included mathematical applications and non-educational related content such as a poster of a popular NFL quarterback that was Rob's favorite player. Rob's desk was located in the back right of the room. However, he never sat at his desk during any observation as he was constantly circulating throughout the room.

Prior to the professional development training, Rob characterized himself as someone who felt comfortable using technology, but used it very little in his class.

> I used Sketchpad in college. So when I came here in my first year, we had laptop carts we could just check out… I got bogged down in just being a new teacher and didn't have a lot of time to explore that with my classes that first year. So I kind of felt like I knew how to use it [Sketchpad] myself, but not how to use it in my classroom. (Rob, Interview 4, December 9, 2010)

In his second year, Rob stated, "I would use it with transformations and maybe in a couple other things" (Rob, Interview 4, December 9, 2010). By the end of the observed semester, Rob stated, "I've used it in almost every chapter to investigate something, so I've used it much more than I have in the past" (Rob, Interview 4, December 9, 2010). As the observations during the semester progressed, changes could be seen in Rob's level of Technology Integration and Instructional Practices.

Observation 1.

Technology Integration.

During the first observation, Rob taught the laws of detachment and syllogism. The premise of the lesson was to help students recognize when either law was being used, how to determine whether a law was being used correctly, and how to create the final statement to make a law true. The law of detachment states that if $p \rightarrow q$ is true and p is true, then q is true as well. The law of syllogism states that if $p \rightarrow q$ and $q \rightarrow r$ are true, then $p \rightarrow r$ is true as well.

For this observation, Rob's Technology Use was categorized as level 0. Rob received this characterization because the only technology he used was the document camera to project notes and worksheets to facilitate his teacher-directed instruction. Within LoTi, use of the document camera is considered level 0. Rob stated during the post-observation interview that he had spent time trying to determine a way to integrate *GSP*, but could not create a file he felt was appropriate.

> I did put some stuff together… But what I decided was we would have so many different if-then statements or so many different conjectures from that we wouldn't be able to come together as a class and have a discussion about it because they all would have seen different things. Or, I didn't want them to have to make a conjecture to be the reason they weren't able to get through the deduction part of the lesson. (Rob, Interview 1, September 20, 2010)

Although Rob did not integrate technology during this class, he did state that he had been using the laptops more in class and was using his website to post *GSP* files for students to use during previous lessons.

Instructional Practices.

During this observation, Rob was categorized as level 2 for Instructional Practices. Rob was considered above level 1 because he did not spend the entire period lecturing. However, Rob was not categorized at level 3 because he did not include high demand tasks or additional opportunities for student discourse. Rob's instructional practices were categorized as level 2 because he primarily taught using direct-instruction, provided limited opportunities for student discourse, and used low demand activities that primarily repeated teacher-provided examples. For example, Rob began teaching the law of detachment with teacher-directed instruction and guided practice problems for approximately 15 minutes. Next students practiced similar problems individually for about five minutes. Rob then selected students to write their answers on the board, which he verified as correct or explained aspects that were incorrect. This pattern was followed for teaching both the law of detachment and the law of syllogism.

Students were provided worksheets for both the notes and practice problems that followed the instructional sequence of the lesson. The notes were fill-in-the-blank and included the guided practice problems that Rob used to demonstrate on the white board. Practice problems emphasized following the taught procedure for each law and were a direct application of the guided practice problems. For example, most practice problems provided the first two statements for the given law. Students were then expected to write the third statement if the first two followed the correct pattern of the law. If the first two statements were not correctly ordered, the students were to write "No conclusion." They were not asked to explain which law the statements were trying to follow or why it was invalid based upon that law. Rob considered using *GSP* to create an exploratory activity, but he chose not to as he felt that doing so, "just felt tacked on to the process of learning the laws. So I ended up not using it, in part because I think the geometric examples are a little harder to grasp" (Rob, Interview 1, September 20, 2010).

During the entire observation, Rob had the highest student engagement and student collaboration at the very beginning of class when he used a deductive reasoning task to serve as an introduction to the law of detachment. For this activity, Rob wrote two statements on the board, "If you have braces, then you get a sucker" and "If you are a freshman, then you get a sucker." Rob told the students to look around the room and determine who should receive suckers and why. Students began doing so and started talking with each other to see who had braces or was a freshman. Rob then asked the class who should receive candy and why. Various students shared, some students even stated that certain people should receive two suckers since they met both criteria. During this activity, students were highly engaged, talked with one another, and were willing to share their observations during group discussion. Later when teaching the law of detachment, Rob referred back to the activity to provide a real-world example of the law.

Student discourse varied throughout the lesson. During the introductory candy activity, student to student mathematical discourse was high. During the time allocated for learning the laws, students did talk with each other, but the majority of the discourse was non-mathematical and often led to off-task behavior. Rob was effective at quickly redirecting the students back to working individually when they were off-task. When class discussion occurred, Rob typically called on individual students to provide an answer, or he asked questions in which he expected a choral response. Rob did not ask students during the discussions to explain, justify, or share alternative methods or solutions. Afterward, Rob recognized that his lesson was heavy in direct instruction. As Rob reflected in the post-observation interview:

> I feel like I talked a lot in this lesson, which I normally don't do for such extended periods of time...Maybe [they could] collect data or be involved in their own type of investigation somehow just because I think it was a little bit too passive combined with my longer periods of talking. (Rob, Interview 1, September 20, 2010)

Summary.

For the first observation of Rob, he was characterized at level 0 for Technology Integration and level 2 for Instructional Practices. The document camera was used to project notes that enhanced his teacher-directed instruction. Additionally, his direct-instruction provided limited opportunity for student discourse. Student engagement throughout the lesson was limited. However, Rob recognized this and reflected that he felt he needed to change his instructional practices, even if he was not completely sure how.

> There was just a lot of "Do as I say" in the lesson today, and I think that's hard. It's hard on them because it's just long. But it's not memorable when it comes to going back to the material… It's just, it's hard for me to wrap my brain around how to teach deductive reasoning… Hopefully a Sketchpad investigation would work perfectly. I just need to come up with the right one, or anything, [maybe] matching if-then statements with a partner. Anything to just get them more involved would be good. (Rob, Interview 1, September 20, 2010)

Observation 2.

Technology Integration.

During the second observation, the lesson began by reviewing slope and transitioned to using slope to explore and create parallel and perpendicular lines. For this observation, Rob was characterized as level 2 for Technology Use. Rob was characterized above level 1 because students used *GSP* to complete classroom activities. Rob was categorized below level 3 because he provided guided demonstrations through most of the pages within the *GSP* file before students were allowed to explore made each activity page, and students had limited opportunities for mathematical discourse.

The *GSP* file Rob used contained four pages with dynamic explorations and one page with written problems. The four dynamic pages had students calculate measurements, drag different lines, make conjectures based upon their observations, and predict which lines would be parallel or perpendicular. Each activity page provided dynamic multiple representations. Each page had questions asking students to individually explore and make conjectures about the constructions using calculations, measurements, and the drag test. For example, the first page was used to explore the slope of a line (Figure 1). On this page, Rob constructed a line with two points. From these two points extended two segments that formed the legs of a right triangle where the line segment between the two points represented the hypotenuse. The text provided a general definition for slope and asked students to use *GSP* to calculate Rise/Run, drag the two points to explore when slope was positive and negative, use the measure option to find the slope, and then create conjectures about the behavior of slope. The second page had students explore the relationship of the slopes of parallel lines. The third page had student determine which lines were parallel from the multiple lines constructed on the page. The fourth page had students explore the relationship of the slopes of perpendicular lines. The final page had students complete practice problem on paper to recognize a pattern in the slopes of perpendicular lines.

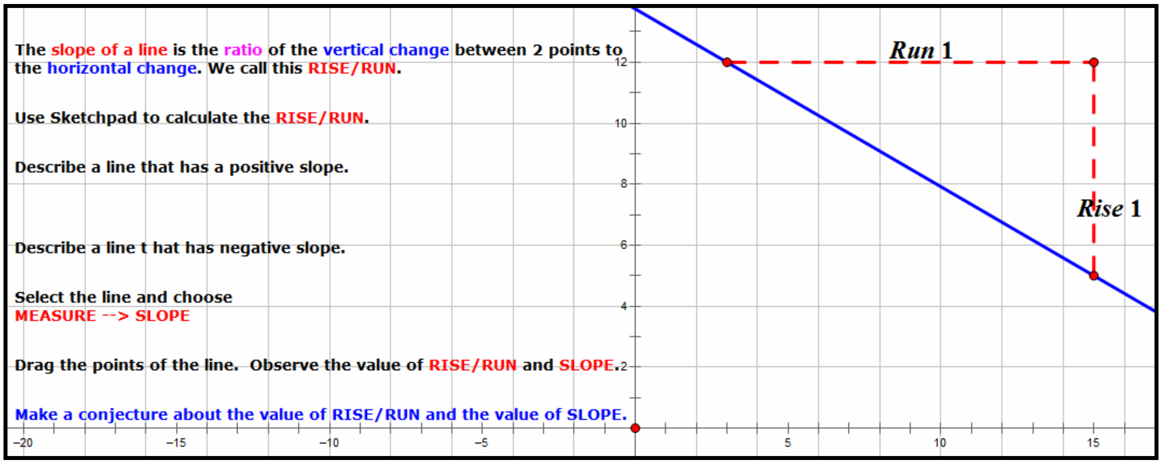


Figure 1: Page 1 of Rob's *GSP* file on Slopes of Lines

When asked why he used *GSP* in this lesson, Rob replied:

> Sketchpad lets you look at so many cases all at once as opposed to taking the time to calculating the slope by hand for two segments, and then two different segments, and two different segments… Hopefully they'll take that to their pencil and paper work and know what the outcomes should be before they do it. (Rob, Interview 2, October 7, 2010)

Instructional Practices.

Rob was primarily categorized at level 2 for Instructional Practices in this lesson. Rob was characterized above level 1 because he tried to use the *GSP* file to help students first explore and then lead a group discussion on the main concept of each page. However, Rob was not categorized as level 3 because he often lowered the cognitive demand of the tasks by interjecting with technical advice about how to complete the task in *GSP*. For example he explained how to measure and provided mathematical suggestions about what students should pay attention to so that they could write their conjectures. Additionally, students were provided only limited opportunities for discourse throughout the class. For instance, before students could explore slope on the first page of the *GSP* file, Rob began demonstrating how to complete each step in the instructions. He then started dragging the line and explaining what was occurring to the slope. This occurred again for page 2 (introduction to parallel lines) and page 4 (introduction to perpendicular lines). Such demonstration before each activity minimized individual exploration. By showing students the solutions before they were able to explore, Rob decreased the rigor of some of the high-order problems he was trying to have students address. During the post-observation interview, Rob justified his demonstrations throughout as being necessary due to the students' limited *GSP* skills. "We're still at the point, you know, where they're not remembering how to measure segments, and now they're getting distracted when you give them time to just do something" (Rob, Interview 2, October 7, 2010).

One problem within this lesson was that Rob's instructions for the first page in the *GSP* file created an opportunity for students to form misconceptions about how to determine when slope would be negative or positive (Figure 1). In his verbal directions, Rob told students to use length measurements. However, length measurements are always positive, thus the slope of the line could never become negative. After allowing students time to explore the first page, Rob realized this mistake. He stopped the class and explained to his students why length measurements were never negative and how this influenced their calculation of the rise divided by the run. Rob altered his plans and had the students use the slope measurement option instead of calculating the rise divided by the run for the other four pages.

Students appeared engaged and on-task throughout this lesson. For example, when Rob provided guided demonstration, every student had the *GSP* file open and was working through each activity individually as well. When students were expected to work individually on each activity in the *GSP* file, most students appeared to stay on-task and complete the activity.

Similar to the first observation, students were not provided specific opportunities to discuss the activities with other students. When students did talk with each other during the exploratory activities, there was a more balanced mix of mathematical and nonmathematical discourse than was observed during the first lesson. On-task discussion often focused on how to complete a task in *GSP*, what each student noticed in the activity, and what each student found for solutions to practice problems.

Even though students personally showed greater engagement in discussing mathematical concepts during exploration, Rob's discussion questions primarily focused on asking students to provide solutions or state their conjectures. Responses from students to these questions were generally choral responses. For example, during the introduction to parallel lines discussion, Rob asked a student what he noticed. The student replied that he noticed that the slopes were the same. Rob agreed and then asked the students, "So if slopes are the same, then lines are?" to which most students replied in unison "Parallel." In this instance, a student gave the answer Rob wanted, so he moved on quickly without probing other students or facilitating additional discussion on the slope of parallel lines.

Students did ask more questions than the first observation, especially within the *GSP* activities. For instance, when exploring slope, a student stated, "When I made my line vertical, I got Rise1 divided by Run1 equaled $1.2x10^{15}$. When I measured slope like you just showed, it told me it was undefined. Shouldn't they be the same?" Rob's replied that this was a limitation of the program's calculator.

In another instance, when Rob was leading the discussion on perpendicular lines, he asked one student, "S1, as you drag it [the line] around, what did you notice [about the product of the slopes]?" S1 replied, "The values changed but the multiplied number always stayed the same." Rob then asked another student, "So S2, what number did you get when you multiplied [the slopes]?" S2 replied, "Undefined or -1. But I only got undefined at one place. Is it both?" Again, Rob stated that this was a limitation of *GSP*. Both of these examples represented missed opportunities where students were trying to understand what undefined slope meant and how it influenced relationships of parallel and perpendicular lines.

Summary.

Rob appeared willing to integrate *GSP* into his class. However, Rob still provided a significant amount of teacher-directed instruction through guided demonstration. This led to Rob being characterized as level 2 for Technology Integration and Instructional Practices. Rob felt this amount of demonstration was necessary to help students use *GSP* correctly. When asked about the challenges of teaching the observed lesson, Rob reflected:

> You know you really still have to encourage them to kind of drag it and test all the different situations and to think about why that's the way it is. I put specific questions in there in response to make conjectures to kind of lead them to do that. (Rob, Interview 2, October 7, 2010)

Rob also had moments when he could have been characterized as level 3 for both categories. For instance, when completing page 3 of the *GSP* file where students were to explore which lines were parallel, Rob only re-read the instructions and reminded students to drag the lines to verify they were always parallel. He then let students start working while he circulated within the room. Students were actively engaged in manipulating lines, measuring slopes, and changing colors to signify lines were parallel. Some students shared with others nearby to see if they were finding the same pairs. Instances like this suggested that Rob was still transitioning in his teaching and learning of Geometry with *GSP*.

Observation 3.

Technology Integration.

During the third lesson, Rob taught similar triangle relationships. Rob's use of technology was similar to the way in which he used technology during the second observation. For this lesson, Rob was characterized as level 2 in Technology Integration. Rob was characterized above level 1 since students used *GSP* to complete classroom activities, but he was not categorized at level 3 because he often used guided demonstrations through most of the pages within the *GSP* file before students were allowed to explore.

This lesson had students explore a five page *GSP* file on proportional parts of similar triangles for half of the period. This file included the following relationships of similar triangles: perimeters, medians, altitudes and two different angle bisector relationships. Each page of the *GSP* file contained directions on how to explore the activity and a question asking students to create a conjecture based on their exploration of the constructions. For example, on the perimeters page Rob had three instructions telling students to calculate the perimeter of each triangle, the ratio of the perimeters, and the ratio of the measures of the two longest sides of the triangles (Figure 2). This was followed with a question asking students to conjecture about what they recognized between perimeters of similar triangles. This question also included in parenthesis that the students were to try dragging before creating conjectures.

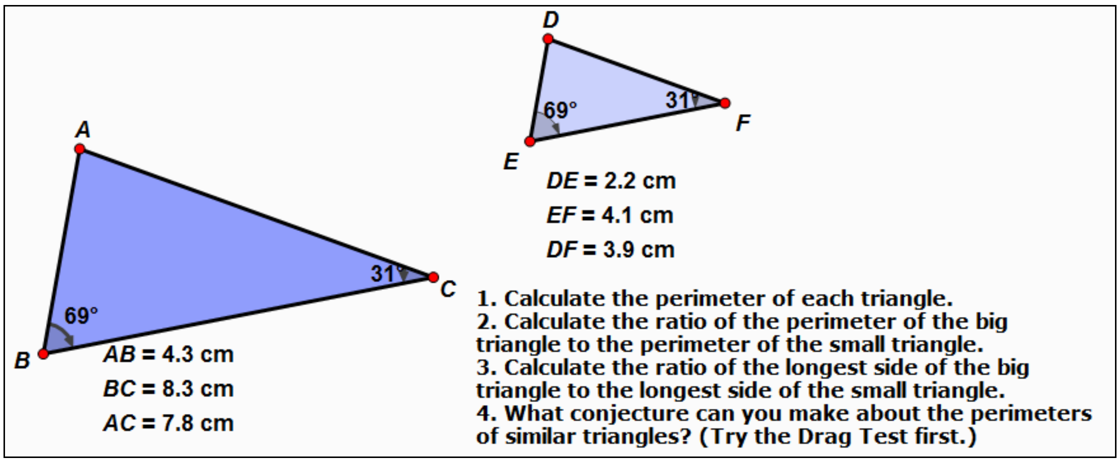


Figure 2: Page 1 of Rob's *GSP* file on Similar Triangle Relationships

Instructional Practices.

Rob's Instructional Practices were coded at level 2 as he struggled with how much input to provide students when exploring and discussing new concepts. Rob was considered above level 1 as he incorporated student-based activities. However, he was not able to obtain categorization of level 3 because students engaged in limited discourse and the cognitive demand of most tasks was lowered by Rob providing demonstrations.

In the first half of this lesson, students individually practiced review problems of the triangle proportionality theorem followed by Rob leading a discussion about how to solve each problem. The practice problems were direct applications of the topic from the previous day. Rob did provide multiple representations to assist students in thinking about the solutions to the problems. This included marking the original diagram projected on the whiteboard, providing the written steps for solving the necessary proportion for the problem on the whiteboard, and verbally explaining why the initial equations were created as well as how to solve each proportion step-by-step.

The second half of the lesson focused on proportional parts of similar triangles using a five page *GSP* file. Rob created a notes worksheet to accompany the *GSP* file on exploring relationships in similar triangles. This structured notes sheet included a fill-in-the-blank explanation for each relationship followed by two examples in which students were to set up the correct proportion and solve for *x*. Students were expected to first follow the directions on the *GSP* page that matched the relationship, explore the relationship based on instructions on the page using calculations, measurements, and the drag test, and then use their newly attained knowledge to fill in the blanks and complete the two problems on the notes sheet.

Rob taught the second half of the lesson similarly to how he taught during the second observation. Students worked individually on each page to explore and make conjectures about the constructions using calculations, measurements, and the drag test. After students individually explored the page, Rob led whole class discussion. However, Rob continued to provide guided demonstration and directions that gave away much of the concepts before students were allowed to explore. For example with the first relationship, perimeters of similar triangles, this intended exploratory activity was turned into a whole-class guided demonstration by Rob (Figure 2).

Rob: There are some directions on this page that we are going to be able to use. They tell us to do some calculations, but remember Sketchpad can do these calculations for us…So what you are going to do to calculate perimeters is very easy. You are going to take your cursor and go up to “Number” and click “Calculate”. Now I don’t even need to type in the numbers, I can just click on the measures. Here comes the difficult part. I have to find the ratio of the perimeters. How do I do that?

Students: Divide

Rob: Again I can use Sketchpad to calculate….It says to do big triangle to small triangle. So I am going to click on the big measure and divide by the small measure. I’m going to drag this up to the top left corner so we can see what is happening....So 3 says to calculate the ratio of longest sides of the big triangle to the longest side of the small triangle….So choose BC divided by EF, hit ok…

Afterward Rob demonstrated how to fill in the notes and set up the proportion for the first example problem. Students worked individually to complete both examples. Once most students had completed both examples, Rob showed the students how to solve each example.

Rob then directed students in the class to click on the second page of the GSP file, medians in similar triangles. While Rob again showed students how to measure and calculate, he did not include any additional statements about the relationship they should recognize. Instead, Rob allowed students time to individually explore the construction and complete the notes and examples on the worksheet. Afterward, Rob reviewed the notes sheet and how to set up each proportion for the example problems. Due to limited time, Rob could not allow students to complete the rest of the file. He instead asked the students what they thought would happen in the cases of the altitudes and angle bisectors in similar triangles. When students provided a choral response indicating that they believed that the ratios would be equal, Rob agreed and showed them how to set up the first example for each on the notes sheet. He concluded class by stating they would explore the final page of the *GSP* file on the second angle bisector relationship the following day.

Although much of his implementation was similar to the second observation, Rob's reflection on his implementation showed growth and understanding. When asked "What challenges did you confront today with this lesson?," Rob suggested that he may have limited the students' opportunity to construct their knowledge by his continued guidance and demonstration.

> I really wonder if they know what it means to have equal ratios. I kind of, we kind of led them towards the proportions we wanted them to write, but do they understand what it means to be proportional and how does equal ratios allow us to say that? (Rob, Interview 3, November 17, 2010)

The discourse within Rob's class was also similar to the second observation. Students were still allowed to talk when completing activities, but they were not expected to share conjectures or their justifications with each other. Students continued to appear more engaged when using *GSP* than during any other portion of the lesson. When *GSP* activities were being completed, the student-to-student discussions that did occur continued to focus on help with using *GSP* or on comparing results to the activity on the given page.

Rob's leading of discussions focused on students providing solutions and rarely included justification or explanation of those solutions. There were also missed opportunities for additional whole class discussion and exploration. For instance, early in the lesson a student recognized that she could create the proportion differently than what Rob wrote on the board and still find the same solution. Instead of having the students explore or even lead a guided exploration on how the two proportions were related, Rob stated that her method was correct but did not represent an understanding the specific theorem.

This dismissal did not seem to deter students during this lesson as they continued to share more of their observations and explanations during class discussions than prior observations. For example, after Rob wrote that the ratio of the perimeters of similar triangles is equal to the ratio of measures of the longest sides, a student interjected:

Student 1: It works for the other sides too.

Rob: That is interesting. I wonder why this is working?

Multiple students shout: Isosceles! Equal!

Rob: No, it's not that.

Student 1: Oh, they're similar.

Rob: Right!

There were additional times in the lesson that Rob asked students to come to the board and work the problems while their classmates finished. Although Rob did not ask the students to explain their work afterward, they showed on the board the equations and how they solved the problem step by step. His post-observation reflection indicated that he recognized the need for more discourse within the lesson. Additionally, Rob also recognized that students were more engaged when using *GSP* that at other times within the lesson.

> I think something about Sketchpad kind of gets them to work on things a little bit more. It's like if I had just handed them a page of sample problems after talking about it without Sketchpad or without anything like that, it's always hard to get them to do that. But I think those little intervals of investigation followed by just a couple sample problems is the perfect amount for them to kind of expand their knowledge. (Rob, Interview 3, November 18, 2010)

Summary.

While Rob stayed primarily at level 2 in Technology Integration and Instructional Practices, areas of growth could still be observed. Rob again used a *GSP* file to serve as the center of his instruction of new material, but interjections with directions and demonstrations reduced the cognitive demand of the original tasks that were posed to students. Rob's reflection on his lesson suggested that he recognized he had limited the cognitive demand of the activities. Additionally, Rob ended with a more positive attitude on the value of *GSP* in motivating and engaging the students in learning.

> I like having the days where we use that because it's a little bit different for me and for the students… Sketchpad takes care of so many things quickly and dynamically, that it changes a lot for us… If nothing else, for the students, they are learning the same thing, but it kind of breaks up the monotony a little bit. I think that goes a long way too. (Rob, Interview 3, November 18, 2010)

Observation 4.

Technology Integration.

The fourth observation occurred during a lesson focused on examining the area of triangles and using triangles to find the area of general quadrilaterals. Throughout this lesson, Rob was consistently characterized as level 3 for Technology Integration. Within this lesson, Rob was considered above level 2 as most *GSP* tasks were of high cognitive demand and students were regularly engaged in mathematical discourse. However, Rob was not characterized as level 4a as there were no real-world connections within the activity.

For the topic of area, Rob utilized a seven page *GSP* file that he used over two consecutive days. The observed lesson focused on the first three pages of the file. The first page included four triangles on a coordinate plane for which students were to use the coordinate plane to help them estimate the area of each triangle. The second page asked students to create a parallelogram using a constructed right triangle (Figure 3). It then asked what they noticed about the constructed parallelogram and how that might help them find the area of a triangle. Finally, page three had two general quadrilaterals. The instructions asked students to find a way in which triangles could be used to find the area of each. Additionally, students were reminded that the height is perpendicular to the base. The constructed height was to then be displayed in red.

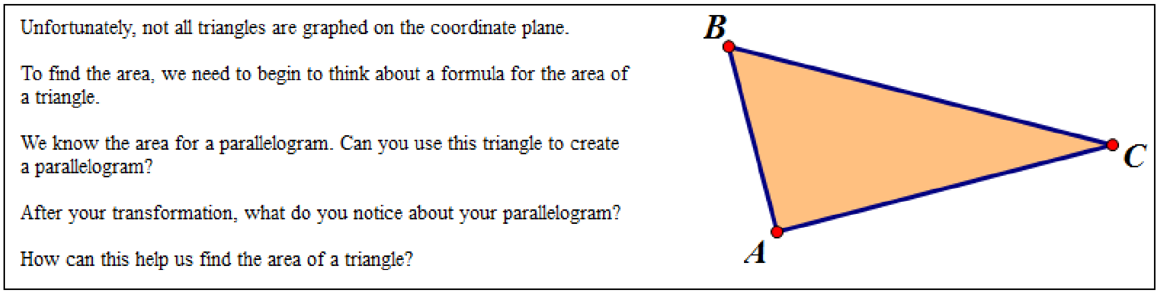


Figure 3: Page 2 of Rob's *GSP* file on Area

The activities on pages two and three were the first time during any of the observations in which Rob had the students construct in *GSP*. In the two previous observations in which *GSP* was used, Rob had every page pre-constructed such that students were primarily measuring and dragging objects. By requiring students to construction, they had to understand the content which they were exploring, analyze and build connections between the various related concepts, and recognize the affordances and constraints of *GSP* to create the dynamic object required in each activity.

Instructional Practices.

During this final observation of the semester, Rob continued to improve such that his Instructional Practices were categorized as level 3. Similar to Technology Integration, Rob was characterized above level 2 because most activities were of higher cognitive demand. Also, the lesson emphasized student inquiry with a significant amount of student discourse throughout the lesson. While Rob emphasized a more learner-centered approach within most activities in the lesson, there was not a real-world connection, thus Rob was characterized below level 4a.

Rob had students involved in the lesson from the very beginning of the class. For the homework review, Rob had homework problems on the board with a student name by each problem. Those students came up and wrote how to solve the problem while Rob checked homework. While Rob did not ask each student to verbally explain his/her work, each student showed the steps he/she used to solve the given problem. Afterward, Rob answered questions about any of the problems. When questions were asked, Rob would draw diagrams when needed and would show multiple methods of solving more complex problems. For example, a student asked how to find the area of a concave dodecagon that had all 90° angles which looked similar to a cross. Rob drew the figure twice on the board. He then showed two different methods for finding the area by using smaller rectangles within the figure. Each time he included not only the drawn rectangles, but also the measures of each rectangle so that it could be seen how to sum the individual areas to find the area of the entire shape.

Once the homework review was completed, Rob transitioned the class to begin the main lesson that utilized the *GSP* file. Rob limited his teacher-directed input in two of the three activities with the *GSP* file. Additionally, Rob improved discourse by having students work in pairs throughout the entire class.

While Rob had students work in pairs extensively for this lesson, his reflections throughout the semester suggested that this was something he struggled with how to do effectively. For instance, during the second observation students worked individually throughout the lesson. During the post-observation interview Rob was asked, "What challenges did you confront during this lesson and how might you deal with them in future lessons?" Rob stated,

> It's hard with a class of 25 to get to everybody's laptops. I debated before we did this today if partners would have been a better idea. The problem I have with partners is one person kind of just sits there and does it all anyway. (Rob, Interview 2, October 7, 2010)

Even after the fourth observation, Rob still had reservations about the consistent use of partners potentially causing disengagement in one of the two students. "I can't do it too often because I feel like it becomes routine and they know they can just sit there" (Rob, Interview 4, December 9, 2010). However, Rob had a different view of partnering students when using *GSP*.

> When I use Sketchpad, I definitely almost always use pairs or small groups in that class, if for no other reason than for technical issues. You know we're using it, but with a lot of premade sketches, constructing to add on to it, students get lost and I can't get to everyone. That definitely helps... [Also,] I think the partners helped them focus on their problems a little bit more. Having someone to kind of keep them on task, to help them when they're stuck was something that worked well. (Rob, Interview 4, December 9, 2010)

On the first page, students were asked to estimate the area of triangles located on a gridded coordinate plane. Once pairs appeared to have completed the activity, Rob asked different pairs to explain what they found, how they found each area, and how they handled partially filled squares when determining the area. Afterward, Rob suggested that while this method could be used for checking solutions for the area of a triangle, using the formula for area would be more helpful.

Rob transitioned to the second page, which asked students to use a constructed right triangle to create a parallelogram (Figure 3). Once created, students were asked to explore their constructed parallelogram and examine how it could be useful for finding the area of a triangle. Prior to beginning, Rob limited his interjections to only reminding students the formula for finding the area of a parallelogram and that this activity would create a rectangle, which was a special type of parallelogram. He then let the student pairs begin working to explore how to construct a rectangle from the given right triangle. After several minutes of exploring, Rob held a quick class discussion on any progress that had been made for constructing the rectangle. Instead of telling students how to create the rectangle, Rob asked for insights from students. Rob constructed exactly what each student recommended to him on his projected file.

Student 1: Copy and paste the triangle.

Rob copies and pastes the triangle in the same page, creating a congruent triangle that was translated to the upper right corner of the screen

Rob: That didn't make a parallelogram.

Student 2: You need to rotate it to fit with the other.

Rob: That won't make a constructed parallelogram, but rotation is a good idea that could help us out.

At this point, Rob showed the class how to perform a general rotation in *GSP*. He also hinted that a non-vertex point on the triangle may be needed. After several minutes, the majority of the class figured out that the midpoint on the hypotenuse was needed to create the rectangle. Rob then facilitated discussion around the questions for the activity. Instead of providing the answers, Rob asked students for their conjectures along with their justifications for each question.

Although Rob created a highly interactive *GSP* activity, his second activity had the potential to create misconceptions between the relationships of the areas of triangles and parallelograms (Figure 3). Instead of having students try to use a general triangle to create a parallelogram, Rob had students use a pre-constructed right triangle. This activity could potentially cause a student to develop a misconception that only right triangles could be used to create a parallelogram. One student even appeared to have this misconception. Although it was not specifically observed when the misconception first occurred during the activity, once the activity was completed, Rob asked the student, "Now you said that you thought it would only work for right triangles. You still think that is true?" The student replied, "Yeah." Rob had to then work out an explanation for why any general triangle could be used to construct a general parallelogram. Rob was asked about this issue during the post observation interview.

Researcher: So is there a reason you used a right triangle versus just a standard triangle for that activity?

Rob: I think it was easier for them to understand what it would take to make a rectangle as opposed to if I said, "What would it have to have if it made a parallelogram?" I think in terms of being able to visualize that, they can all picture a rectangle much more than they can picture a parallelogram. (Rob, Interview 4, December 9, 2011)

The other potential misconception could have been that since the area of a right triangle uses both legs, the area of any triangle would be the product of the two shorter sides of the triangle. This was a concern that Rob mentioned during his interview. “They are still going to need to learn that the height is always a perpendicular segment…They always have trouble with that. They just want to pick the two numbers that they see and multiply” (Rob, Interview 4, December 9, 2010). However, Rob created a construction that could potentially reinforce this idea and did not recognize it as such.

While the first two activities were learner-centered, Rob reverted to teacher-directed guided demonstration for the third activity on how to use triangles to find the area of a general quadrilateral. Instead of allowing students time to explore how triangles could be used, Rob demonstrated step by step how to draw in a diagonal for the quadrilateral, construct the perpendicular segment to represent the height for each triangle, calculate the area of each triangle, and add the area of the two triangles together. The student pairs followed along and created the constructions while Rob demonstrated. Rob then had the pairs try to replicate the procedure to find the area of a second quadrilateral on the *GSP* page. This guided demonstration reduced the cognitive demand of the activity as students were no longer required to critically think through the relationship of using multiple triangles to find the area of a quadrilateral.

With the time left in class, Rob had students complete and turn in five problems on the area of triangles and general quadrilaterals from the textbook. Students were allowed to work with their partner, but each was required to turn in his/her own work. The two problems strictly on the area of triangles already had the heights drawn in with the measurement for the base and height given. The two general quadrilateral problems also had the diagonal drawn in and measurements for the height and base of each triangle provided. The fifth problem required students to use higher order thinking as they were provided a rectangle with the diagonal drawn, one side given, and one of the angles formed by diagonal was marked as 30°. While the first four problems were direct application, this fifth problem forced students to either draw upon their knowledge of right triangle trigonometry or recognize the special right triangle relationship in 30-60-90 triangles.

Summary.

Throughout the lesson, Rob showed a greater balance between teacher-directed and learner-centered instructional practices compared to earlier observations. Students were expected to work together to explore and build understanding between the areas of triangles and quadrilaterals. During class discussions, students were expected to provide the solution/conjecture along with the explanation/justification for their solution/conjecture. If students explained how to do something on *GSP*, he would do exactly what they said so that the class could examine not only their suggestions, but also the way in which they were sharing their suggestions. While Rob included teacher-centered instruction at times, such as the guided demonstration for the final *GSP* activity, Rob primarily used learner-centered practices that allowed students the opportunity to explore and answer questions in a manner that guided instead of instructed.

Rob's reflection of the lesson signified that much of his intention was to have students build a deeper understanding of the connections between various concepts they had been learning. "I thought that realization was really powerful for them, and understanding how everything is intertwined. I didn't mind the fact that it was slower…but the time we spent I think was worth it" (Rob, Interview 4, December 9, 2010). Because Rob worked hard to facilitate throughout the lesson, students appeared to be highly engaged throughout the entire lesson. Very little off-task behavior was noticed at any point. More importantly, the increased student collaboration allowed for a significant increase in the amount of student mathematical discourse. Throughout the lesson, the only nonmathematical discussions heard occurred once a set of partners finished an activity.

Influence of the Professional Development.

In the backdrop of the four observations was Rob's involvement in the professional development prior to and during the observed semester. When asked about the role of the professional development in his lesson planning or teaching, Rob consistently stated throughout the semester that he felt the professional development helped him, directly and indirectly with lesson planning as well as teaching. For instance, when asked if he used any concepts from the Summer Institute or online professional development for the second observed lesson, Rob stated, "I wouldn't say directly, but one of the things you know that I was really trying to think about was kind of what breaks a sketch and when does it not work (Rob, Interview 2, October, 7, 2010)." Rob also mentioned that it helped him realize how to use other tools in *GSP* like the *Snap Points* option for graphs so that the points would always stay at integer coordinates. For the third observed lesson, Rob mentioned using different transformations taught during the Summer Institute in the hidden aspects of the constructions of his *GSP* file. After the fourth observed lesson, Rob also attributed some of the pedagogical methods from the Summer Institute as being influential as well. "Having talked about transformations on Sketchpad a little bit, but also understanding how to guide them appropriately without giving away the answers helped me (Rob, Interview 4, December 9, 2010)."

In reflecting on the overall influence of the professional development, Rob felt that the Summer Institute had had a major influence on his teaching throughout the semester. As he stated:

> I think at the Institute, what you guys did such a good job of is showing an idea and then letting me refine it and expand upon it like "I didn't even know I could do that…" I think it [allowed] me to do a lot of investigating that I haven't been able to do in the past, where I've kind of been like "Oh, look. This is the way it is. Memorize that." Now I can take twelve minutes and set something up so that they get right to what I want them to see. I think I've gotten a lot better at that, and I think the institute has shown me that it is a lot easier than what I might think it may be. (Rob, Interview 4, December 9, 2010)

Characterization of Rob throughout the Semester.

Throughout the observed semester, Rob worked to plan and implement lessons that integrated active student learning through the use of *GSP* activities. As can be seen in Figure 4 and Figure 5, Rob transitioned from limited use of technology prior to the observed semester to using *GSP* within his geometry class on a regular basis. As the semester progressed, Rob allowed more student collaboration, which his reflections suggested was due to his increased use of *GSP*. Finally, while Rob struggled throughout the semester between providing teacher-directed guided demonstration and allowing student exploration, he began to allow more exploration and student sharing as the semester progressed. As Rob stated in his final reflection:

> You know, it's always a toss-up of you don't want to give away too much, but you still want them to get there. A lot of them were like, "Well just tell us the answers." I think with time, I've become more comfortable with saying the right things to get them to the think the right thoughts. (Rob, Interview 4, December 9, 2010)

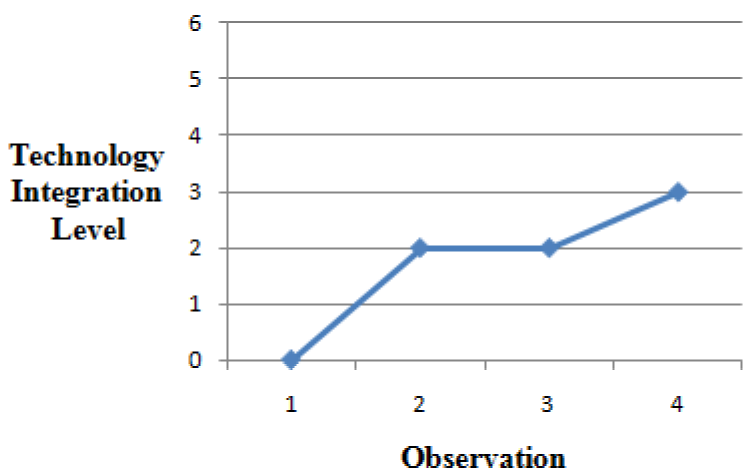


Figure 4: Rob's characterization of Technology Integration through the Four Observations

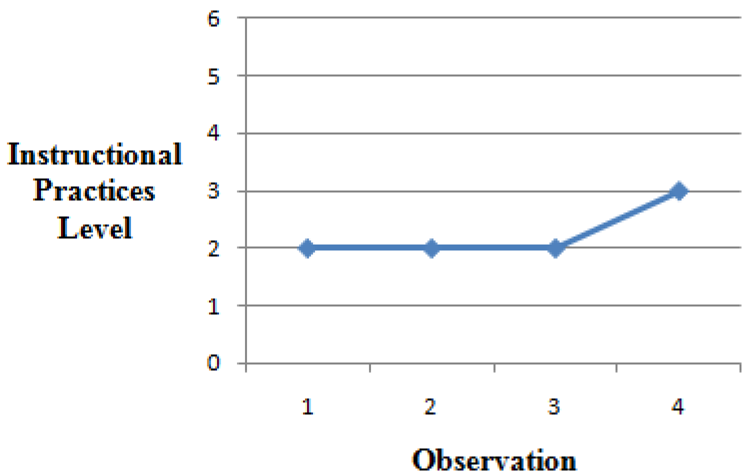


Figure 5: Rob's characterization of Instructional Practices through the Four Observations

Although some of the files that Rob created were restricted and included potential opportunities for students to develop misconceptions, Rob reported that he was attempting to use technology and *GSP* more often than prior years within his class, and he felt it was influencing his teaching. As Rob stated, "I've used it in almost every chapter to investigate something. So I've used it much more than I have in the past" (Rob, Interview 4, December 9, 2010). When asked about his personal improvement for the coming semesters, Rob stated that his biggest task would be reviewing and refining what he had already created as well as continuing to create new and innovative activities.

> Until this semester, I hadn't really been putting together that. Now I have a whole chunk of Sketchpad files that I can come back to. Now it's not so much, "I want to demonstrate this." But it's, "I'm already demonstrating this. How can I make it better?" or "How can I make it more effective?" or "How can I let them do more of it?" That's just something I just think is going to come with time and my comfort in

teaching it, but also my ability to critique the things I've already put together as my skills in whatever program or software I'm using continue to develop. (Rob, Interview 4, December 9, 2010)

Case 2: Reese

Reese was a case of a teacher whose classroom management inhibited her ability to regularly integrate successful technology-enhanced lessons. During the observed semester, Reese was beginning her fifth year teaching and fourth year teaching geometry. Reese received her teaching license through a one year Master's of Teaching program in Mathematics Education at a large university in North Carolina prior to her first year of teaching. All observations took place during Reese's fourth period Honors Geometry class. The class averaged 22 students. There were 8 male and 14 female students.

The arrangement of Reese's classroom remained the same during all four observations. A SMART board was mounted in the center of the front whiteboard. Reese had a table in the center of the room for the mobile projector needed for the SMART board and her laptop. Desks were aligned in rows facing the center of the room creating a U-shape. Posters of mathematical topics, mathematical applications, and other non-educational posters such as a cartoon movie poster were displayed on the walls. Reese's desk was in the back right of the room. However, she never sat at her desk during any observation as she was constantly circulating throughout the room.

Prior to any professional development training, Reese had limited use of *GSP*, and she had never used it in her class.

> I had seen *GSP* during my MAT program. We visited the Mac lab during one of our night sessions, spring 2006 and looked at what the program could do. I had not worked with the program since then until this summer. (Reese, Email, February 22, 2011).

During the spring of Reese's first year, she received a SMART board. Prior to the current semester, the SMART board was her primary technology tool. When asked about her use of the SMART board, Reese stated:

> I have used it daily since I have had it… I used the Notebook software to prepare notes and/or problems before class… I also used the Notebook like I would a whiteboard to work out problems. I have the student workbooks on my computer so I would project those and fill in the answers on the SMART board. The Geometry text comes with PowerPoint, and I have used that with the board to work out the answers. I would project the internet only if I needed to direct students to a particular page and feel the need to show the navigation to the page. (Reese, Email, March 20, 2011)

As the first semester of her fifth year progressed, subtle changes were observed in her Technology Integration and Instructional Practices as Reese worked to integrate *GSP* throughout her lessons. Other factors appeared to influence and limit the amount of change that occurred.

Observation 1.

Technology Integration.

In her first observed lesson, Reese taught the side-side-side (SSS) and side-angle-side (SAS) theorems for congruent triangles. For this observation, Reese's Technology

Integration was categorized as level 2. Reese was considered above level 1 because students used *GSP* to complete activities. However, she was considered below level 3 because the *GSP* activities were of low cognitive demand.

During this lesson, Reese created a five-page *GSP* file to serve as notes for the concepts of SSS and SAS congruence. While Reese used *GSP* to teach the new material, the file was limited in how it incorporated the tools of *GSP* for student exploration. For example, the first page was created to have students explore SSS. Instead of creating dynamic triangles that would maintain congruence when manipulated, students were instructed to create static congruent triangles with the provided measurements (Figure 6).

1) Draw $\triangle ABC$ with the given measurements. (Hint draw $\overline{AB}$ and $\overline{AC}$ then connect to make $\overline{BC}$.)

2) Draw $\triangle DEF$ with the given measurements.

3) What do you notice about the two triangles?

$\triangle ABC$
$\overline{AB}$ = 1.5in.
$\overline{AC}$ = 2 in.
$\overline{BC}$ = 2.5 in.

$\triangle DEF$
$\overline{DE}$ = 1.5in.
$\overline{DF}$ = 2in.
$\overline{EF}$ = 2.5in.

Figure 6: Page 1 of Reese's *GSP* file on Triangle Congruence

Two of the pages in the file were created for written responses and no constructions. For example, the page following SAS had the question, "Is it possible to draw $\triangle$DEF with the given measurements so that it is NOT congruent to $\triangle$ABC? If so show how." The other page provided a definition for the term included angle and a constructed angle with the included angle marked. The final page included the following construction (Figure 7). The isosceles triangle and the angle bisector were constructed to maintain their properties.

However, this construction was only used as a static representation, and students did not individually explore or manipulate the triangle. Instead, Reese led a guided discussion on how to prove the two triangles were congruent. She also did not utilize any of the dynamic features of the construction while leading the discussion.

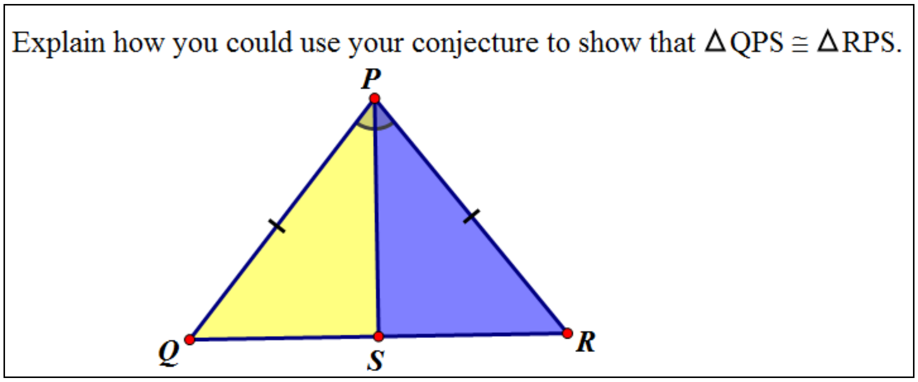


Figure 7: Page 5 of Reese's *GSP* file on Triangle Congruence

It appeared during this observation that Reese was trying to incorporate all available technologies to teach her class. In addition to using *GSP*, Reese also used the SMART board. During homework, Reese projected the solutions onto the SMART board. When students needed help with the *GSP* file, Reese would stand and use the touch-screen functionality of the SMART board with *GSP* to create, measure, and demonstrate anything that confused students. However, the use of *GSP* was limited in this lesson as the file represented a digital version of a paper-based worksheet on triangle congruence Reese found in her textbook.

> [For] the Sketchpad piece, I took an existing worksheet from one of the books and that used a ruler and a protractor and I turned it into something they could use with

Sketchpad. Instead of saying, "Okay, measure it with this ruler, you know, use Sketchpad. Let that measure it for you and, put it in a document." (Reese, Interview 1, September 27, 2010)

Instructional Practices.

Throughout the first observation, Reese's Instructional Practices were characterized as level 2. Reese was categorized above level 1 because she did not lecture during the lesson. However, Reese was characterized below level 3 because the student activities throughout the observation were of low cognitive demand. For example, prior to learning about SSS and SAS triangle congruence with *GSP*, Reese had students complete a textbook worksheet that reviewed the foundations of triangles. The worksheet included 13 low demand problems and three moderate demand problems. Two of the low demand problems provided a diagram with all the expressions in the exact location needed to create the equation for the exterior angle theorem of triangles. Another set of low demand problems stated that ΔMNO and ΔGHI were congruent, provided a segment or angle from one triangle, and asked students to identify the corresponding congruent object from the other triangle.

Although Reese encouraged collaboration and student-to-student discourse in each of the activities, a significant portion of the discourse was nonmathematical. For instance, while Reese suggested students work with a partner while completing the triangle review worksheet, several students were observed being off-task throughout the time allotted for completing the assignment. Reese tried to limit this off-task behavior by circulating the room, answering individual questions, and asking students to continue working on the review. Once Reese moved away, students often went back to talking about nonmathematical topics. Students acted similarly when provided the final ten minutes of class to complete their homework.

Student engagement improved when Reese transitioned to having students work on the *GSP* file. Reese allowed students time to create and learn on their own throughout the activity. At the beginning, Reese reminded students that this file served as their notes for the day. She also reviewed how to create and measure segments as well as how to label and change labels of points and segments using the SMART board and *GSP*. Reese allowed students to begin without any further guidance other than suggesting them to talk and collaborate. As students worked through the file, Reese walked around observing and helping students. Although she did have to ask a few students to remain on task, the majority of students were focused on completing the activities for each *GSP* page.

Group discussion and review occurred similarly with each activity in the lesson. If students had just completed problems, Reese would ask a question and the majority of students would provide a choral response. If students provided a mixed response, Reese would state the correct answer and ask if anyone had a question. If so, Reese would go to the SMART board and complete the problem using diagrams and equations as needed. This sequence for review occurred during the homework review at the beginning of class, the worksheet review on the foundations of triangles prior to the *GSP* activity, and the triangle congruence classification worksheet after the *GSP* activity. Reese rarely asked for justification or an explanation to posed questions. Only on the final problem of the homework review did a student provide reasoning for her solution.

Students appeared comfortable and willing to ask questions throughout when they were confused. One student asked during the foundations of triangles review if the congruent triangles' letters could be in a different order. Reese responded that the order could be different as long as corresponding parts matched. Students were also willing to question mathematical language in the activities. When providing solutions to the transformation questions within the homework review, the textbook had asked students to use the terms slide, flip, and turn instead of translate, reflect, and rotate. One student asked, "Why aren't we using the correct transformations?" Reese responded, "Because the book doesn't expect you to know those terms yet."

The final group discussion occurred with the final page of the *GSP* file. This page included a high cognitive demand task that had the potential to allow students to explore and prove triangle congruence using a dynamic construction. Reese projected the page and led a class discussion on how to prove the two triangles in Figure 7 were congruent. Reese did facilitate the discussion instead of directly instruct the students on how to prove the triangle congruence.

Reese: The last thing I have up here is the "Think about it." Could I prove that these two triangles are equal? Is there a way I could show that the blue and the yellow triangle are equal?

Student 1: Those two angles look right. (points to where the angle bisector intersects the base of the isosceles triangle)

Reese: Are they marked?

Student 2: Oh, the two angles at the top marked.

Reese: Ok, I have ∠QPS congruent to ∠RPS. What else?

Student 3: QP = PR

Reese: Ok. Now where is that third side? (waits)

Student 4: PS?

Reese: Why do you say that?

S4: They're sharing it.

Reese: Good! We have ∠QPS congruent to ∠RPS and QP = PR because they are marked as congruent. We also know PS is a shared side. So we have shown the triangles are congruent by SAS.

While Reese helped students identify the components of one possible proof, she missed an opportunity for students to consider multiple proofs and unique insights that may have been created through individual exploration. For instance, the first student was actually correct that the angles she pointed to were right angles because the large triangle was isosceles. Had Reese allowed students to explore, they may have had the potential to recognize not only triangle congruence but also special relationships as the given segment was an angle bisector, altitude, and perpendicular bisector of the isosceles triangle. Reese did not write the proof on the page while students were explaining how to prove the two triangles were congruent. Students did not appear write this on their page either. As this file represented their notes, students did not have any recording of the problem with the highest cognitive demand within the file.

After completing the *GSP* notes file, students were given a second textbook worksheet which was of low cognitive demand. For this sheet, students had to identify whether two triangles were congruent, and if so they were to state whether it was because of SSS or SAS. Reese turned this worksheet into a group discussion and told students to call out whether the two given triangles were SSS, SAS, or not congruent. If there was mixed responses, Reese would state the correct solution and provide reasoning.

Reese finished the lesson by allowing students the final ten minutes to work on the homework. They were permited to collaborate, while Reese circulated and answered questions. Student engagement was mixed as about half the class appeared to work on the homework problems. The textbook homework included low to moderate demand problems with four classifications similar to the second worksheet, two problems that required students to use graphing and the distance formula to determine congruence, and one proof. However, the proof was of low cognitive demand because all the needed pieces for the proof were in the given information.

Summary.

Reese was characterized as level 2 for Technology Integration and Instructional Practices. While Reese integrated the use of technology into her classroom via the SMART board and *GSP*, her activities did not include challenging problems and explorations that would require students to use higher order thinking. In reflecting on the lesson, Reese recognized there may have been ways to increase the cognitive demand with different activities.

Researcher: And is there anything that you would alter from the lesson, if you were to re-teach it?

Reese: Potentially. I might add those, the sliders. I did get that e-mail, by the way, that you had, where you fold the pieces down and just let them play with those a little bit more, just to see, "Okay, well, this does happen every single time. It's not just these set measures that work out" and just give them a little bit more time to kind of play with the technology there. (Reese, Interview 1, September 27, 2010)

Prior to the observation, Reese had emailed the researcher asking for a dynamic file on triangle congruence. This file contained different pages for SSS, SAS, ASA, AAS to explore each of the triangle congruencies. It also included a page with SSA to show why the angle must be included to prove triangles were congruent. The sliders on each page were used to alter the length of potential corresponding sides or angles, depending on the theorem, of the triangles. One triangle stayed constructed while the second triangle had three attached segments that were dragged at the vertices to try and create the congruent triangle. However, Reese did not have an opportunity to create questions with the emailed *GSP* file, thus she used her file with static images.

Although Reese used *GSP* in a limited fashion, she recognized its potential and planned to continue using it in her class.

> If they just had a pencil and paper, I'm not going to get about half of them to actually, "Okay, here's this measure and I put it here and then I put this other one" and, you know, to actually play with it and to work with it as you do with the technology

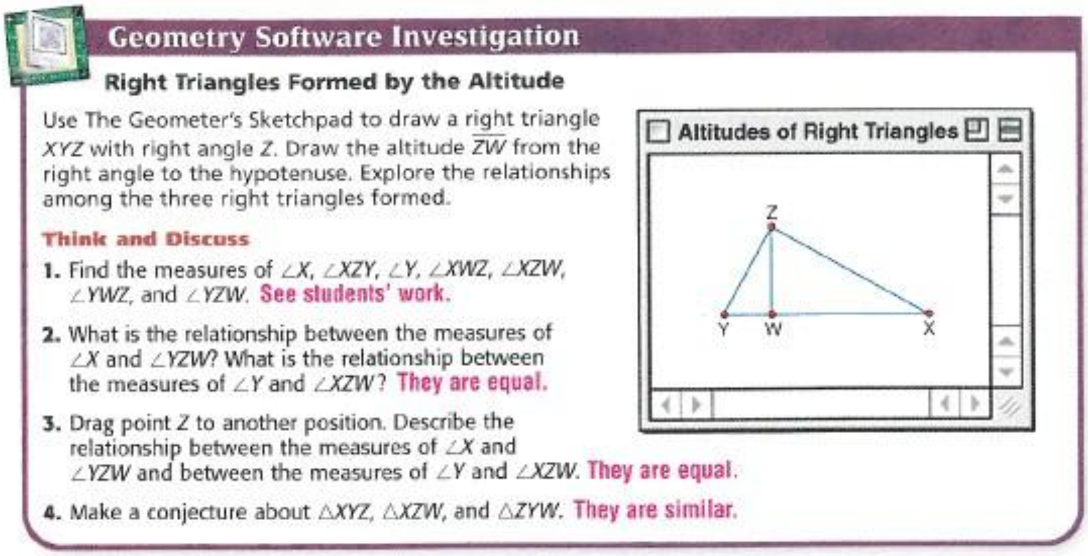
because it is fairly accessible to them. [With *GSP*] they're able to get in there and manipulate it, whereas, with pencil and paper, they might not be as willing to do that. (Reese, Interview 1, September 27, 2010)

Observation 2.

Technology Integration.

In Reese's second observation, she taught geometric mean relationships in a right triangle with an altitude from the right angle. Reese was considered above level 1 for Technology Integration as students used *GSP* to work through an activity from their textbook, *Glencoe Geometry* (Boyd, Cummins, Malloy, Carter, & Flores, 2005), that suggested using *GSP* to explore and recognize the similar triangles formed in a right triangle with an altitude (Figure 8). While the lesson had potential to be categorized as level 3 as the *GSP* activity was of higher cognitive demand, Reese eventually led a guided demonstration to help students construct their right triangle to answer the given questions. By doing so, the cognitive demand of the activity was decreased, thus characterizing her as level 2 for Technology Integration.

Reese's expectation with the *GSP* activity was for students to construct a right triangle, construct the altitude from the vertex of the right angle to the hypotenuse of the triangle, measure different angles and segments to compare triangles within the construction, and answer the four questions about the relationships within the construction. These steps were to culminate with students recognizing the three similar right triangles that were created by the altitude inside the right triangle. Having just completed similarity of polygons, Reese hoped the students would then recognize how to create proportions to find missing segment measures and equations to find missing angle measures. Reese then planned to share how these proportions created geometric mean problems.



Geometry Software Investigation

Right Triangles Formed by the Altitude

Use The Geometer's Sketchpad to draw a right triangle *XYZ* with right angle *Z*. Draw the altitude $\overline{ZW}$ from the right angle to the hypotenuse. Explore the relationships among the three right triangles formed.

Think and Discuss

1. Find the measures of ∠*X*, ∠*XZY*, ∠*Y*, ∠*XWZ*, ∠*XZW*, ∠*YWZ*, and ∠*YZW*. **See students' work.**
2. What is the relationship between the measures of ∠*X* and ∠*YZW*? What is the relationship between the measures of ∠*Y* and ∠*XZW*? **They are equal.**
3. Drag point *Z* to another position. Describe the relationship between the measures of ∠*X* and ∠*YZW* and between the measures of ∠*Y* and ∠*XZW*. **They are equal.**
4. Make a conjecture about △*XYZ*, △*XZW*, and △*ZYW*. **They are similar.**

Figure 8: GSP Activity from *Glencoe Geometry Teacher's Edition* (Boyd et al., 2005, p. 343)

This planned activity appeared to be of high cognitive demand as students would be required to create, explore, and conjecture. However when implemented, several students followed the literal instructions and created a sketch instead of a construction. When Reese told them they needed to construct instead of sketch, many students appeared to have the technical issues with *GSP* as they struggled to construct the right triangle and the altitude. As the time allotted for the activity continued, the majority of the class showed signs of frustration with many appearing disengaged once they could not figure out how to construct the right triangle. When Reese realized that her goal for the activity was not occurring, she abandoned *GSP* and shifted teaching geometric mean via direct instruction using a SMART Notebook on the topic from the previous year. The Notebook file included the definition of geometric mean, practice problems for finding the geometric mean of two numbers, and then provided a method for finding segment measures in the right triangle with an altitude using geometric mean.

Instructional Practices.

Reese was characterized as level 2 for Instructional Practices. Reese was considered above level 1 as she did not lecture the entire class. However, Reese was categorized below level 3 as students' inability to create constructions with *GSP* shifted Reese from using a learner-centered exploration to using teacher-directed instruction to cover the material within the lesson.

Reese began class with a review of the previous night's homework. The review included Reese asking students to call out solutions. When students had questions, Reese would draw diagrams and equations on the board while explaining the solutions. Students were not asked to provide explanations or justifications throughout the review.

From the homework review, Reese transitioned the class to the *GSP* activity. Reese told the students to open their textbooks to the page with the activity. Reese tried to help students begin by giving them some hints for what constructions would be needed to create the right triangle and altitude.

Reese: What do we know about the two sides of a right triangle?

Students: They're perpendicular

Reese: So to make sure the triangle stays right, make the two sides of your triangle are perpendicular. Go and get started making your right triangle. You can use the book on your computer or the one under your desk to complete the activity.

From here, students were provided little scaffolding. Students began attempting to make a right triangle while Reese circulated. Some created a sketch of a right triangle instead of a constructed right triangle. When Reese noticed this, she reminded the students that the triangle must be constructed using perpendicular lines. Students worked together to figure out how to do this. One student went to at least three different pairs to show them how to construct perpendicular lines in *GSP*. After about 10 minutes, many students had quit trying and were having off-task discussions. Reese recognized this and brought the class back together. She demonstrated on her SMART board how to construct a perpendicular line hoping this would help students get back on task. After five more minutes and still many students appearing confused, Reese demonstrated how to construct the entire right triangle. However, multiple students were off-task and not paying attention, so Reese showed how to construct the right triangle a second time. She then asked the students to continue with the activity stating that all they needed was to construct the altitude.

After another 15 minutes of students partially working while Reese tried to circulate to help individual students, Reese decided to abandon the activity and move to providing direct instruction using her SMART Notebook file. While Reese lectured, students wrote the notes and examples. When there were example problems, students worked individually. When reviewing the problems, Reese would call on different students asking for the next step. However, the students were not asked to justify their reasoning for that step. Once the practice problems were completed, Reese assigned homework for the final 20 minutes of class from the text book. She also told students they were expected to stay quiet the rest of the time. The majority of students worked the rest of class quietly and individually on the problems.

Once Reese transitioned to direct instruction, the practice problems and assigned homework problems were of lower cognitive demand. These problems were direct application of examples provided in the notes and focused on only the easiest types of problems that could be completed with the right triangle and geometric mean. Reese recognized that the cognitive demand of the tasks was low and that the problems assigned did not address higher-order thinking. As she stated, "The students needed to learn more about geometric mean with the triangles as many could only work the simple problems and not the complex problems they needed to think about" (Reese, Interview 2, October 21, 2010).

This lesson showed a dramatic shift in instructional practices. Reese wanted to focus on allowing students to learn through exploration and collaboration with *GSP*. However, lack of structure kept most students from moving beyond trying to construct the triangle. Their frustration led to disengagement. Several groups sat and talked until Reese would come by. She would try to guide them and help them move forward with the activity, but once she left, many groups would revert to off-task discussion.

Unlike the first observation, student engagement was highest during the direct instruction. Most students were quiet, attentive, wrote the notes, and tried the practice problems. They were even engaged when told to work quietly on the homework. This possibly could have resulted from the specific structure provided during this part of the lesson. Students knew the expectations and were provided adequate information to attempt problems. They were also willing to ask questions when they were confused.

Afterward, Reese recognized the technical difficulties that occurred, and how they influenced the lesson.

> I decided to use technology for some of the lesson because I wanted to see if the students could figure out the similar triangles on their own. No, it did not go exactly as planned because the students did not construct the right triangle correctly the first time and then some stopped working on the activity. (Reese, Interview 2, October 21, 2010)

Summary.

Reese tried to provide a lesson that would have been characterized as level 3 for Technology Integration and Instructional Practices. She wanted to facilitate student exploration and promote student discourse through a challenging interactive *GSP* activity. As she stated, "I wanted to see if students could figure out the similar triangles on their own" (Reese, Interview 2, October 21, 2010). However, the activity did not provide enough structure or guidance to allow students to appropriately attempt exploring the relationships of the similar triangles within the construction. This resorted in Reese relying on direct instruction to ensure that students received notes on the given lesson. As she reflected:

> The challenge came from letting the students have too much freedom with the technology. In the future I would set up the triangle with the students first, then have them measure the angles and complete the activity. (Reese, Interview 2, October 21, 2010)

Observation 3.

The third observation for Reese was unique in that it was in many ways two disjoint lessons. In the first half, Reese led a review on reflections and translations, followed by a quiz on the two transformations. In the second half, students explored rotations and dilations through a guided question worksheet using *GSP*. This led to the lesson being characterized based on the two different halves of the observation, which will be referred to as observation 3a and observation 3b.

Observation 3a Technology Integration.

During observation 3a, Reese was characterized as level 1 for Technology Integration. Reese was not categorized above level 1 because only she used technology, and she used it to enhance her instruction. During this half of the lesson, the SMART board was used with *GSP* to show how to find the solution for the warm-up problem and to project a Notebook file with homework solutions. This happened after Reese spent about five minutes trying to get the projector and SMART board to work correctly. Even after she had it working, the board still presented problems for several minutes, which forced Reese to instead use the white board for part of the homework review. When the SMART board was used, it was used to enhance what Reese was explaining. Once the board started working, Reese wrote her examples, drew her diagrams, and provided solutions using the Notebook software. Additionally, Reese wrote two of the quiz problems on a Notebook file that she projected during the quiz.

Observation 3b Technology Integration.

In contrast, Reese was categorized as level 3 for Technology Integration during observation 3b. For this part of the observation, Reese was above level 2 as student completed high demand activities using *GSP*, yet was below level 4a because there was no real-world connection within these activities. As students completed the quiz, Reese instructed them to pick up the worksheet labeled “9-3 Rotation” on the front side and “9-5 Dilation” on the back side. No preconstructed file was used to accompany the worksheet. Instead, the worksheet provided detailed directions to help students explore each transformation using *GSP*. Each student was expected to create, explore, and conjecture about each transformation through the guided steps on the worksheet. For example, the rotation activity walked students through creating a triangle, rotating the triangle, manipulating the pre-image to examine its effect on the image, and examining ordered pairs between the image and pre-image for rotations of 90° and 180°. Below the activity were notes that included how rotations of 90°,180°, and 270° would influence a generic ordered pair, (x,y) and two example problems for students to complete. When reviewing both activities, Reese used the SMART board with *GSP* to create the transformations and solutions suggested by students.

Observation 3a Instructional Practices.

During the first half of the observation, Reese was characterized as level 2 for Instructional Practices. She was considered above level 1 but below level 3 as this half of the lesson had students complete low demand problems and Reese share how to solve each problem with limited input from students. While Reese checked homework, she expected students to complete one warm-up problem from the textbook. This was the first observed class in which Reese used a warm-up, and it was likely due to an email correspondence Reese had between observations with the researcher. In submitting the observation 2 summary as part of the member check, the following email conversation occurred between the researcher and Reese.

Researcher: … I have one other suggestion. Try giving students a warm-up problem or two for when they come in and you check homework. When I started doing this with my classes, I noticed they got to work quicker and they were more focused when we began. Just a thought… (Researcher, Email, October 25, 2010)

Reese: … As for the suggestions, thanks. I have done warm-ups in the past but sometimes I find it takes longer to get students working, then do the warm up and then homework. So that's why you haven't seen one. But from time to time I do them… (Reese, Email, October 28, 2010)

Researcher: Warm-ups can definitely be a double-edged sword with time. I think a way around it taking too long is to use the SMART Notebook capabilities. Create the problem with the timer (from the gallery) on the page. When the timer goes off, have the students pass in the warm-up. You put at least a "completion grade" on them for the first week (even if you don't actually use them). If they start slacking and wasting time,

> start collecting them again. I did this with my students and they got into the habit pretty quickly. (Researcher, Email, October 28, 2010)

Reese took part of the advice in that she began using warm-ups, but she did not create any consequences for not completing them. The problem given during this observation was of higher cognitive demand as it required students to create the image of a triangle after two transformations. However, with Reese checking homework and not requiring the warm up to also be checked or graded, only about half the class collaborated with students nearby to complete the warm-up. The other half discussed off-task topics and did not attempt the warm-up. When Reese began reviewing the warm-up problem, one student stated how to perform the double transformation. As the student explained how to create the image, Reese performed each step using the transformation options in *GSP*.

For the homework review, Reese provided the majority of the solutions and explanations for each problem primarily because less than half of the students completed the homework. This visibly bothered Reese. While checking homework and seeing how many did not complete it, Reese said, "Guys, this is pitiful." When reviewing the last problems from the book, Reese began by stating, "For those of you who took the time to do your bookwork, here are the answers." This frustrated Reese because the textbook problems were to be the high demand, honors-type homework problems. They included performing multiple transformations, using reflection lines that were not the coordinate axes, and finding either the pre-image or image. Since her SMART board would not work at the beginning, Reese drew several of the solutions on the whiteboard while she explained how to solve the problems. Any questions she asked to students were of low cognitive demand that allowed for choral responses.

Afterward, Reese gave students about 25 minutes to complete a quiz on transformations. The quiz was directly from the textbook assessment book. Reese had students complete two additional problems she projected with the Notebook file on the back of the quiz. All ten problems were of lower cognitive demand. For example, the six graphing problems stated the coordinates of each vertex of the pre-image and then stated the transformation that was to occur (e.g.-reflect over x-axis). No problems included high-demand concepts such as multiple transformations, non-axes reflection lines, or finding the pre-image instead of the image. Still, several students appeared frustrated and took the entire time to complete the quiz. As Reese reflected, "They seemed a little bit frustrated because half of them didn't have the work. The ones that did, they seemed okay" (Reese, Interview 3, November 12, 2010).

When asked about whether the review and quiz went as she planned, Reese shared her own frustration.

> The beginning, trying to get them to go over homework, not so much… As far as doing the actual book stuff [, the four high demand problems], hardly any of them did it…Those would be challenge/bonus questions, you know, the honors level-type questions and, when half of my honors kids don't bother to do it, it becomes frustrating. (Reese, Interview 3, November 12, 2010)

Observation 3b Instructional Practices

In contrast, during observation 3b students were engaged, collaborated, and completed activities that required higher cognitive demand. For this reason, Reese was categorized as level 3 for Instructional Practices for observation 3b. Reese was not considered above level 3 because there was no real-world application involved with the activities. Students began working individually through the guided questions activity sheet on both rotations and dilations while others finished the quiz. As the majority of students finished, they began discussing their solutions and transformations in *GSP* with one another. During this time, the majority of student discussion appeared on-task and focused on completing the worksheet. Reese continued circulating, observing students as they worked, and answering questions.

As Reese began leading the review on rotations and dilations, she provided additional technical instruction on *GSP* such as explaining how *GSP* chose the first point of rotation and how that can be changed. While reviewing each activity, Reese would sketch the pre-image and then call on students to explain what they did to create the image, why they did it, and how that influenced the image. For the majority of the group discussion, Reese limited her own input and allowed students to share their insights.

In Reese's reflection, she considered the student learning of rotations and reflections to be successful. "I think that they did well using the Sketchpad to actually explore it and then be able to kind of see the relationship and then discuss that relationship" (Reese, Interview 3, November 12, 2010). Reese attributed this success to her use of a guided questions worksheet.

> I've found that if I have a structured kind of worksheet or questions for them to work through, that they are very good about, "Okay, I'm looking at this. I need to do this process next. I need to… okay, she wants me to find this. How do I find this? Okay, here's how I do it." And they are very good about walking themselves through projects, as long as I have it outlined step-by-step, which is why I did the nice little worksheet for them. (Reese, Interview 3, November 12, 2010)

This suggested that Reese was continuing to learn from her experiences of teaching with *GSP*. Although not mentioned, Reese possibly recognized there was not enough guidance in her earlier activities like in observation 2 and likely started to learn what components helped make such activities be successful for her class. By the time they completed this activity, students seemed familiar with technical skills of *GSP*, which could likely be attributed to Reese continuing to change and improve her use of technology in teaching new concepts.

Summary.

Observation 3 suggested that Reese was trying to improve her Technology Integration and Instructional Practices. Although Reese struggled with engaging students during observation 3a, she showed significant improvement when helping students learn new material throughout observation 3b. Several unique factors caused much of the struggle during the first half: her students uncharacteristically did not complete their homework, the SMART board and projector quit working and had to be restarted, and many students did not work through the warm-up. However, engagement became high and students were willing to work together and share both in small and large group discussion during observation 3b. As Reese stated about the students during the second half,

> I thought that they did pretty well today. Several of them seemed to hit on what was changing and things that were different, and I heard some of them helping each other out. I think that they actually did pretty well, as far as today goes. (Reese, Interview 3, November 12, 2010)

Reese even talked about the possibly having students complete *GSP* projects that incorporated multiple transformations to extend their thinking on transformations within *GSP*.

> Reese: That is the plan… to do some sort of, like, one of the little projects and let them see what happens when they can use them together or try and animate something so that it changes, so that they can have a little bit more fun with it instead of just the basics. So, the past few days have been building basics. We're going to do something a little different on Monday and then they will have their test, and hopefully it will go well.
>
> Researcher: So, what are you thinking, on Monday, one of the activities from the summer, or do you have something else?
>
> Reese: Probably. I was actually going to ask you if you would recommend. I know that I have the Ferris wheel one [from the online professional development]. And then we did the spiral one this summer. Something like that, just so that they can have a composition, like a couple of them together that they can let something move and they can see how that would actually work.
>
> Researcher: Okay. We can look and see. (Reese, Observation 3, November 12, 2010)

Her comments suggested that she recognized the utility of activities she had learned from the professional development sessions and that she was willing to receive help from the researcher in making her classroom activities be successful. Reese emailed the researcher the following week stating that the activity suggested had been successful. “The spiral went well in both of my classes and I gave the Ferris wheel to the honors students as extra credit. The Ferris wheel worked for the majority of the students and some even added people to the ride” (Reese, Email, November 18, 2010). As Reese had never used *GSP* to teach prior to this year, this was a major shift in learning opportunities for her students that probably would not have occurred without the professional development Reese was receiving. It also suggested that Reese was willing and interested in continuing to find ways to integrate technology into her instructional practices.

Observation 4.

Technology Integration.

Reese’s final observation focused on surface area and volume of spheres as well as ratios between area and volume. For this final lesson, Reese was characterized as level 1 in Technology Integration. Reese was categorized above level 0 as she used technology to teach her lesson. However, Reese was considered below level 2 as only she used technology to enhance instruction throughout the lesson.

Reese did not use *GSP*, but she used the SMART board with a Notebook file to provide notes and practice problems throughout the lesson. Students did not interact with the board as it used primarily to project slides. The primary reason Reese relied on direct instruction via the SMART Notebook software was that *GSP* is limited in exploring volume and surface area of three-dimensional figures. Since *GSP* calculates measures of segments and angles, it is not possible for *GSP* to create accurate three-dimensional figures for students to measure and explore. When asked why she decided to use the technologies she did, Reese replied, “Well, certainly, I mean, we have the Sketchpad stuff, but I don’t know how to do the volume in there” (Reese, Interview 4, January 4, 2011). This suggested that even though she did not use *GSP*, Reese considered it and had a desire to use it for teaching and learning. This desire was reinforced when Reese’s reply to lesson alterations was, “Anything with Sketchpad in it” (Reese, Interview 4, January 4, 2011).

Instructional Practices.

For her final observation, Reese was categorized as level 2 for Instructional Practices. While Reese was above level 1 as she did not lecture the entire class, she was below level 3 as there were primarily low demand activities throughout the lesson. Although Reese was limited in her ability to integrate technology due to the topics for this lesson, Reese did not try to integrate any type of collaborative, interactive activity to engage students either. As Reese stated, “I just went with something that was fairly easy to use to put problems up on the board and just have them plug in their calculators and give me answers that way” (Reese, Interview 4, January 4, 2011).

The fourth observation started very similarly to observation 3a. Students were given warm-up problems projected on the SMART board to complete while Reese checked homework. Like observation 3a, about half the students worked on completing the six problems. The other half sat talking off-task. Reese twice told the class to begin working on the problems with little change in student behavior. Reese did not check or grade who actually completed the warm-ups afterward which possibly led to students not taking it seriously.

The review of the warm-up problems was different from prior observations in that Reese called on students to not only share solutions, but to also explain how to solve each problem. As the student explained the solution, Reese would write the name of the figure, the generic formula for its volume or surface area, the formula with the measures substituted in, and the final solution. However, Reese did not include the units on any of the solutions even though the measures all had units.

In contrast, when Reese reviewed the homework, she only projected the solutions. Reese then asked students which problems they wanted to see worked. Although students remained passive throughout the review, Reese worked to thoroughly explain step by step how to solve the given problem using figures, diagrams, equations, etc.

As Reese transitioned the class to the new material of spheres and ratios, she provided each student with a notes worksheet. Reese first provided direct instruction on how to solve for spherical volume and surface area as well as how to use the ratio between area and volume to solve different problems. This instruction lasted for approximately 10 minutes. For the next 25 minutes, Reese projected nine problems one at a time. For each problem, students worked through the problem individually. After providing time, Reese asked students for a choral response for the given problem. If they provided the correct solution, Reese went to the next problem. If there was confusion or mixed responses, Reese explained how to solve the problem. The first five problems were of low cognitive demand as they were direct application of the notes. The final four problems were of high cognitive demand.

For instance, one problem asked, “Which has a greater volume, a hemisphere where the diameter equals two times the radius, r, or a cylinder with radius, r, and a height equal to r?” This problem required students not only to know the volume formulas, but also determine a method for comparing the two formulas. However, for all four problems only Reese explained how to solve each problem.

After the nine practice problems, Reese gave students a worksheet from the textbook on volume and surface area of spheres. The worksheet was direct application of the notes and did not include any high cognitive demand questions. Additionally, while students were encouraged to work together, they were again mixed between on and off task behavior, even with Reese continually walking around the classroom. When reviewing the worksheet, Reese called on students to provide solutions, but she did not ask for justifications or explanations. Students were given the final ten minutes to work on their homework. Some students were observed working on the homework while others continued to be disengaged and off task.

Reese’s reflection did not show concern about student engagement, but she did recognize that the cognitive demand could have been higher for this class. When asked what students learned and what they still need to learn, Reese stated:

> I think that they learned how to use the formulas and to plug stuff in. Perhaps, just extending it onto the appropriateness of, you know, I need to use this formula when I see this shape, I need to use this ratio when I have these certain two objects, and the comparison between the different types of objects… probably a little more extending that. (Reese, Interview 4, January 4, 2011)

Similarly when asked about how she might alter the lesson for future use, she reflected, “It was pretty simple. I would probably add some more challenging-type problems to it” (Reese, Interview 4, January 4, 2011).

Summary.

While Reese attempted to use *GSP* in every other observed lesson, the material of this lesson did not provide an opportunity to do so. The inability to use a *GSP* activity for volume influenced Reese’s lesson planning as she did not provide collaborative or engaging activities. Instead, Reese focused on direct-instruction to quickly cover the concepts. As she stated, “This is the last lesson that we had to do for the semester and so, in trying to be as compact as possible, I gave them the notes and just worked examples” (Reese, Interview 4, January 4, 2011). As a result, a significant portion of students were disengaged throughout the lesson.

Influence of the Professional Development.

Throughout the semester, Reese did not often specifically mention her professional development experiences. However, several of her comments indirectly related to influences of the professional development. For instance, in observation 3 Reese suggested that some of her transformation lessons were influenced by the Summer Institute. She also mentioned successfully using activities that she first completed at the Summer Institute and online professional development. When asked about her personal growth with *GSP*, Reese stated, “[My understanding of] Sketchpad has definitely come a long way. I mean, I knew how to do some pretty simplistic stuff, but I know how to do a lot more now and a lot more connected-type stuff instead of just simple basics” (Reese, Interview 4, January 4, 2011).

Characterization of Reese throughout the Semester

Throughout the semester, Reese worked to integrate *GSP* into her lessons with mixed results as can be seen in with figures 9 and 10.

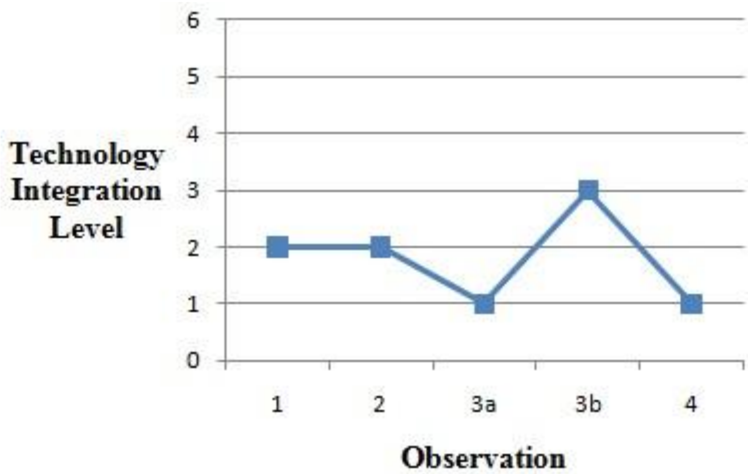


Figure 9: Reese's characterization of Technology Integration through the Four Observations

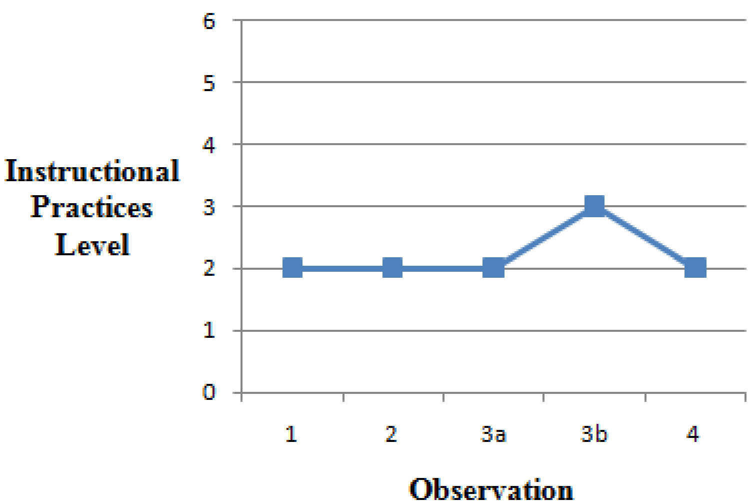


Figure 10: Reese's characterization of Instructional Practices through the Four Observations

Even when she did not use *GSP* in observation 4, Reese still shared in her interview that she wanted to but could not determine how. Reese struggled with student engagement throughout different portions of each observation, such as warm-ups and non-structured activities. However, this semester was a learning process for Reese in determining how to use *GSP* in her lessons. As Reese reflected:

> My kids, especially the one you've been observing, have come along with the technology. I have let them use it more. They are more free to kind of do things on their own, or I can say, "Okay, do this sketch" and they can do it. So, I think that, as the semester progressed, we used it more and more until I got to the point where I don't know how to do, you know, certain things in it… everything that I could find something for, I think that we used Sketchpad for it. (Reese, Interview 4, January 4, 2011)

This statement suggested that Reese recognized she had limitations in her understanding of *GSP*, but also that she recognized *GSP* had limitations in what topics could help her students explore. For example, Reese stated that she did not use *GSP* for surface area and volume as these are topics that *GSP* cannot specifically address. However, she also stated that she did very little with *GSP* for exploring circles, which is a concept that could use *GSP*-based activities. "With circles, I used it some to show a couple of topics, but not all of the topics…We did the angles, but we didn't do the measures of the segments" (Reese Interview 4, January 4, 2011).

Although Reese had difficulty in effectively integrating *GSP* into observed lesson, she stated that she felt *GSP* allowed her to change her way of teaching, such that students were allowed to explore and collaborate more than prior years.

> It allows, especially with that upper-level class, for them to kind of figure things out… for them to look at it… so, I'll say, "Okay, make this sketch… what do you notice?" and then we'll put the theorem up there instead of, before, where I was just saying, "Okay, here's this theorem… here's a couple of examples." You know, now, they can figure that out, and I think that letting them have that ability has changed. (Reese, Interview 4, January 4, 2011)

Finally, when asked how she may improve using *GSP* in the future, Reese responded that she felt she should start earlier using *GSP* and introduce it with engaging, introductory activities such as different activities shared during the professional development opportunities. She felt this would make a positive difference with her second semester students.

> Last semester, the kids didn't have the computers yet, so I couldn't start on the first day, saying, "Okay, let's play with it." This semester coming up, I will have two classes that will already have computers. So, being able to start, you know, day one and day two, say, "Here, we have this program. Let's play with it a little bit"… I think that that will start to help. You know, the sooner they see it, the sooner they're more comfortable with it. (Reese, interview 4, January 4, 2011)

Case 3: Sarah

Sarah was a case of an experienced teacher who struggled with transitioning from teacher-centered to student-centered instructional practices. During the observed semester, Sarah was beginning her twenty-second year teaching and tenth year teaching geometry. Sarah received her license as part of her undergraduate degree at a medium sized university in North Carolina. All observations took place during Sarah's second period honors Geometry class. The class averaged 30 students. There were 11 male and 19 female students.

The arrangement of Sarah's classroom remained the same during all four observations. A SMART board was mounted in the center of the front whiteboard. Sarah had a table in the center of the room for the mobile projector needed for the SMART board and her laptop. Desks were aligned in rows facing the center of the room creating a U-shape. One wall contained posters primarily of mathematical topics in additional to a few posters of Sarah's alma mater. Sarah's desk was in the back right of the room. However, she never sat at her desk during any observation as she was constantly circulating throughout the room.

Prior to any professional development training, Sarah regularly used her SMART board and document camera to enhance her instruction. However, Sarah stated that she had tried using *GSP* a few times before, but felt it was too complex.

> I had previously tried GSP in my classes, but I didn't feel comfortable with it. I didn't feel it was intuitive or easy for the students to follow. It seemed to take up a lot of instructional time that I did not have. (Sarah, Interview 2, October 21, 2010)

As the fall semester progressed, positive changes could be seen throughout Sarah's Technology Integration and Instructional Practices.

Observation 1.

Technology Integration.

During the first observed lesson, Sarah reviewed angle relationships created from parallel lines cut by a transversal line and began teaching the relationships of slopes between parallel and perpendicular lines. Sarah was characterized as level 1 for Technology Integration for her teaching of the lesson. Sarah was considered above level 0 as she integrated the SMART board and SMART Notebook software throughout her lesson. However, Sarah was categorized below level 2 as she primarily used the technology to support the lesson's activities.

To begin the class, Sarah displayed a warm-up problem in SMART Notebook. After checking homework, Sarah solved the problem in Notebook as well. When teaching the concepts of slope and the relationships between parallel and perpendicular lines, Sarah used a premade Notebook file that included notes and practice problems. Sarah did ask students to share their work for the practice problems in the file as well, but their use with the SMART board was no different than if they had written a solution on a whiteboard. Sarah also used her document camera similar to an overhead projector to share the homework solutions and review how to solve problems with parallel lines cut by transversal lines.

Sarah did conclude her class with a technology assessment in which she gave students a *GSP* quiz. This quiz required students to create four pages. On the first page students constructed a set of vertical lines and a linear pair. For each object, they were to label, name, and measure each angle. Also they had to find the sum of the measures of the two angles in the linear pair. Page two required students to create a triangle and quadrilateral, label each vertex, measure each angle, and provide the sum of the measures of the angles for each shape. Page three asked students to construct two parallel lines cut by a blue transversal, find the measure of each angle, and place each measurement at its corresponding angle. The final page asked four low-demand questions about the constructions such as “Vertical angles are always ______.”

In her post-observation interview, Sarah mentioned that although she did not use *GSP* to teach the relationship of slope in parallel and perpendicular lines, she had begun using *GSP* for other topics like angle relationships in parallel lines cut by a transversal line.

> I had actually created one in Sketchpad and had it ready to go when they came in. And then I had them create one and had them measure the angles and actually try to figure out the connections between the alternate interior angles and corresponding angles. I had them also construct, basically, just two lines of a transversal and showed that, if you didn’t make the lines parallel, that the correlations, that the angles weren’t true. (Sarah, Interview 1, September 17, 2010)

Instructional Practices.

Sarah was characterized as level 2 for Instructional Practices for this observation. Sarah was considered above level 1 as she did more than lecture. However, she was categorized below level 3 because the activities, other than the *GSP* assessment, were of low cognitive demand. Questions posed during group discussion of problems were also of low demand questions. However, students were willing to ask questions when they were confused or had different methods for solving a problem. For instance, during the review of parallel lines cut by a transversal line, the following dialogue took place:

Sarah: (shows Figure 11 from the homework using the document camera) The first thing you need to do is find your parallel lines. How many transversals are in the diagram?

Students: 2

Sarah: So we need three lines to look at relationships. (Sarah covers one of the transversals). Now we have these two angles. What's the relationship?

Students: Consecutive interior

Sarah: So if the top one is 90, we know the bottom must be 90 as well. So, 3y + 18 = 90.

Student: I did 3y + 18 + 90 = 180. Does that work?

Sarah: That's the same. (Sarah moves on to second transversal and next problem)

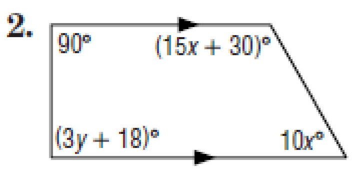


Figure 11: Chapter 3-2, problem 2, Glencoe Geometry Study Guide and Intervention (2005)

The question raised by the student suggested that she was trying to understand the various relationships and was willing to ask questions when confused. In response, Sarah only stated that both angles were 90 degrees and did not provide reasoning why both equations were the equivalent. In contrast with a different problem, Sarah had students help solve the problem and explain their reasoning at each step.

Sarah: (shows Figure 12 on document camera) So this one has a lot of parallel lines, who can help us get started?

Student 1: I know that 2y + 106 = 180

Sarah: Why?

Student 1: Because they are a linear pair.

Sarah: Student 2, now what do we know about x and 106?

Student 2: They're a consecutive interior, so they have to add up to 180 degrees.

Sarah: Good, so we know it has to be 74. Now let's look at these top two…

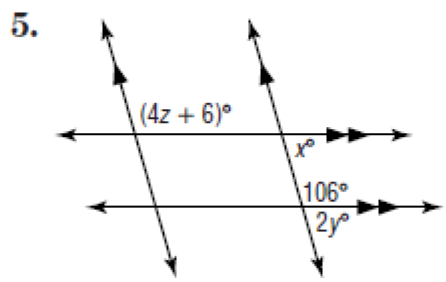


Figure 12: Chapter 3-2, problem 5, Glencoe Geometry Study Guide and Intervention (2005)

Similar patterns were followed throughout the teaching of slope relationships in parallel and perpendicular lines. Sarah would provide direct instruction and examples, but she would also ask various types of questions that included choral response questions, low demand individual questions, and questions which students were required to explain their steps for solving a problem. Students remained engaged and on-task throughout the entire lesson. When given practice, students worked individually; most students did not speak to anyone. The students were still on-task and engaged. These problems were direct application of problems provided in the notes and did not incorporate higher demand tasks.

Although not observed, Sarah reflected that she felt this was a talkative class which she had to closely manage. This in turn influenced her questioning.

> They're a very social group, so I try to really monitor. Or there are times when I'm teaching that I just call their name and they go back to what I'm doing and that just kind of refocuses them. By me trying to basically monitor them and "popcorn questioning," it kind of keeps them attentive most of the time. (Sarah, Interview 1, September 17, 2010)

To finish the lesson, Sarah gave the students a *GSP* quiz to determine their proficiency in basic constructions within the program. Students were given approximately the final 30 minutes of class to complete the quiz. They worked individually and quietly. Several students were still working as class finished. Sarah told them to find time to email her their completed file by the end of the day.

Summary.

During her first observation, Sarah was characterized as level 1 for Technology Integration and level 2 for Instructional Practices. Sarah provided a few opportunities for students to explain how they arrived at solutions to their problems. While *GSP* was not used to learn new material, Sarah used it to both assess their understanding of the program and revisit topics covered in prior units. In this manner, Sarah was able to both assess technical skills needed to use *GSP* while reinforcing content. This quiz also helped Sarah recognize potential adjustments in the amount of allotted time she may need to make for future activities using *GSP* since several students did not finish the quiz by the end of class.

> Nobody has had experience with Sketchpad until [this semester]... It's still very new. And, like everything, some just were very quick with it... And then some are just still, not struggling, but just are not comfortable and not quick with it. They can find it, if the time is there. So I probably needed to give them about 10 more minutes today. (Sarah, Interview 1, September, 19, 2010)

While Sarah did not utilize *GSP* for teaching during this observation, it appeared that she was providing scaffolding for its future use. By quizzing students on *GSP*, she had an opportunity to both learn their current skill level and identify how she may need to structure instructions to help build better understanding of the technical use of *GSP*. As anticipated from the final activity, Sarah began to integrate *GSP* into activities throughout all later observations during the semester.

Observation 2.

Technology Integration.

During her second observation, Sarah taught the relationships in special right triangles, (right triangles with angle measures of 45-45-90 or 30-60-90). For this observation, Sarah was characterized as level 3 for Technology Integration. Sarah was considered above level 2 as students completed high demand tasks with *GSP*. She was categorized below level 4a since no real-world problems were included in the lesson. Sarah continued to use her SMART board with SMART Notebook throughout the lesson. At the beginning of class she projected a Notebook file with the warm up problem that had students find missing segment measures of a right triangle with the altitude from the right angle. When solving the warm-up, Sarah used the Notebook file to mark on the diagram and to work out each of the equations to find the missing measures. Also similar to the first observation, Sarah projected homework solutions with the document camera.

To teach the relationships of special right triangles, Sarah used *GSP* with a Word document worksheet In the *GSP* file, Sarah created two pages. One page had a constructed 45-45-90 triangle, and the other had a constructed 30-60-90 triangle. Each page included the angle measures and side measures of the triangle (Figure 13).

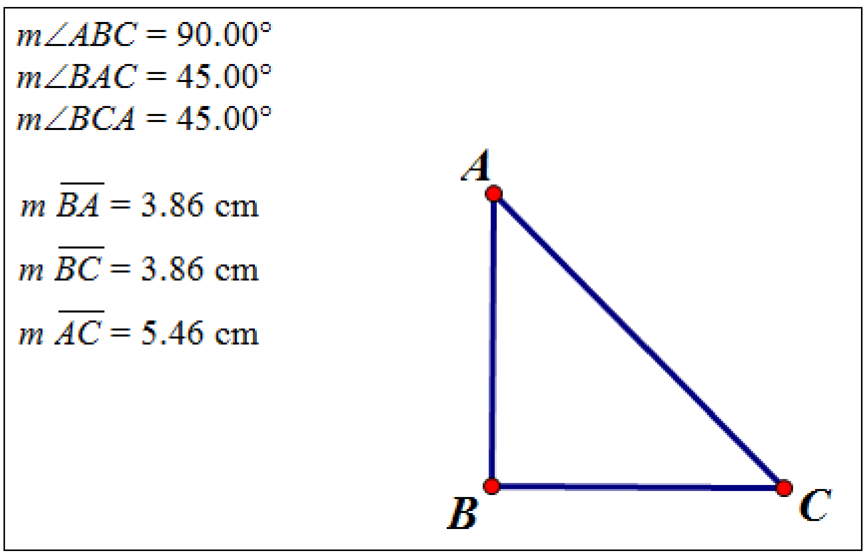


Figure 13: Page 1 of Sarah's Special Right Triangles *GSP* File

The accompanying worksheet had students fill in a table for each of the special right triangles. The 45-45-90 triangle table had students provide the three segment lengths and the ratio of the hypotenuse divided by a leg. The 30-60-90 triangle table had students provide the three segment lengths, the ratio of the hypotenuse divided by the shorter leg, and the ratio of the longer leg divided by the shorter leg. Each table included six rows. Verbal instructions were given that the students were to drag each construction to create six different triangles, each with different measures to fill in each row. They were also instructed to describe patterns they observed. After students were provided opportunities to explore, Sarah led guided discussions using *GSP* with the SMART board to share students' conjectures.

By incorporating a dynamic preconstructed *GSP* file for teaching special right triangles, Sarah allowed students to explore and build conjectures about the relationships between the segment lengths of the triangles. When asked why she decided to use *GSP* for this lesson, Sarah stated, "Usually, this lesson is difficult for them to remember. They get it that day and then, later on, they forget. So, I thought that if they could actually see the connection themselves, then maybe they would retain it" (Sarah, Interview 2, October 21, 2010).

Instructional Practices.

For this observation, Sarah was categorized as level 3 for Instruction Practices. Sarah was considered above level 2 as the majority of the activities were of higher cognitive demand and students participated in building a collective understanding for the relationships between the segment lengths of each special right triangle. However, Sarah was characterized below level 4a as there was no real-world problems integrated into the lesson.

The warm-up and homework review were very similar to the first observation. While Sarah checked homework, students worked quietly on completing the projected warm-up problems. When reviewing the warm-up and homework problems, Sarah would ask low demand questions that would result in choral responses. Students were willing to ask for help with problems that confused them from the homework.

As Sarah transitioned to teaching special right triangles, she asked students to download and open the *GSP* and Word files from her wiki. Sarah explained they were to drag the triangles at least six times in *GSP*, and write the values into the correct table in the Word document. She also explained the shorthand terminology for each of the ratio columns in the Word file. For example, she explained that $\frac{\text{Hyp}}{\text{L}_\text{S}}$ meant they were to divide the hypotenuse length by the length of the shorter leg. Finally, Sarah told students to use the calculator in *GSP* to find the ratios. Sarah demonstrated how to enter values by typing them in. One student stated, "You can just click on the values." Sarah agreed and showed this as well. She had students begin with the 30-60-90 triangle.

While Sarah did not explicitly promote student to student discourse, many students discussed what they were finding with classmates nearby. Most appeared engaged and working to explore possible relationships within each table. One even got excited and started talking loudly towards Sarah who was on the opposite side of the room.

Student: I am noticing a pattern!

Sarah: You are? Well keep it secret for a little longer.

Student: I ain't done, but one more and I see a pattern.

Sarah: Still complete your chart and make sure your pattern continues to hold.

While students completed their charts, Sarah continued circulating the room, checking student work, and answering questions. During the review, Sarah first had students come to the board and write one of the rows from their tables. She then asked students to describe any patterns they noticed. Different students shared that they found the first column to always be 2 and the second to be 1.73. Sarah had the students plug the square root of three into their calculator to show them that the long leg was more accurately written as the square root of three times longer than the short leg. Sarah then explained what this meant in terms of the triangle.

Sarah: So this is the actual definition of a 30-60-90 triangle. So the smallest side is x (draws on *GSP* file). Now you just found that the hypotenuse was twice the size, so it is 2x (draws on *GSP* file). Then you found that the larger leg was square root of three, which means it is $x \bullet \sqrt{3}$.

To connect back to the activity, Sarah explained the pattern for 30-60-90 triangles using one of the rows that had been filled in by the students. Sarah then opened SMART Notebook and provided examples for students to try. These examples required students to use the pattern as well as remember how to simplify radicals. Students worked quietly, but then checked their solutions with students nearby. When reviewing, Sarah called on individual students, had them provide the lengths, and asked them to explain how they found the different lengths.

Sarah had the students follow a similar pattern for the 45-45-90 triangle. Students individually manipulated the construction and filled in their chart. Afterward, students provided examples and stated that they noticed the final column was always 1.41. Sarah had students plug the square root of two into the *GSP* calculator to see that the hypotenuse was more accurately the square root of two times longer than the legs. Sarah again provided the pattern for the 45-45-90 triangle, related it back to the student-created chart, and provided examples for students to try.

To end class, Sarah allowed students to use the final ten minutes to begin their homework on special right triangles. Most students stayed on task and worked to complete their homework. The problems were a mixture between low and high demand problems. For example, one 30-60-90 problem provided the short side as 4 and asked students to find the other two sides. In contrast, another problem had a picture of an equilateral triangle with the altitude drawn and only the altitude length provided and asked students to find all missing lengths.

Summary.

During this observation, Sarah found a way to utilize *GSP*'s dynamic nature while allowing students the opportunity to begin building patterns and connections within special right triangles. While students were not asked to work with a partner or discuss in small groups, many would discuss what they were finding. To build connections and understanding, Sarah provided examples and homework that had students not only look at a single triangle with one of three lengths provided, but she also included problems of higher cognitive demand that required them to use other concepts to help find the lengths. Interestingly, Sarah was not sure afterward whether she would complete this activity in class again.

> If I had to do it again, I might actually have them, let that be maybe a homework assignment because they really didn't need me to help them investigate. They could actually investigate it at home, and then we could have come in and discussed it

> because some were really quick filling out the table and others were slower, and so there was some downtime for some students. (Sarah, Interview 2, October 21, 2010)

Like the first observation, Sarah continued to be concerned about student off-task behavior even though this again was not observed. In a later interview, Sarah recognized that much of her concern about student behavior was due to her structured teaching over the past 22 years. "I have always been really structured, so giving away some of that for students to explore and discover has been difficult. I have been trying hard to make it happen though in class" (Sarah, Interview, November, 12, 2010). This was an area of her instructional practices which Sarah continued to work on and reflect upon throughout the rest of the semester.

Observation 3.

Technology Integration.

During the third observation, Sarah taught relationships in circles between central angles, inscribed angles, interior angles, and their intercepted arcs. Sarah was characterized as level 3 for Technology Integration. Sarah was considered above level 2 as students used *GSP* to complete high demand activities, yet was below level 4a as no real-world activities were incorporated into the lesson.

Like the first two observations, Sarah used SMART Notebook to project the warm-up problem on arc measures and worked the solution on the same page. For the formal lesson on angle relationships within circles, Sarah used *GSP* to share notes and explore the relationships between the different angle and arc measures in circles. While students opened a blank *GSP* file, Sarah opened a two page file. The first page included a circle with a constructed inscribed angle and a hide/show button that when clicked provided a definition of an inscribed angle. With this topic, students were given verbal instructions to construct a circle with a central and inscribed angle, and to measure each angle and its intercepted arc. They were then instructed to move the points and write down the three measures five times. From this data, Sarah told them to try to find any possible relationships they noticed.

The second page included a circle with two constructed intersecting chords that went through the center of circle and a hide/show button that when clicked provided a definition of interior angles. Students were given verbal instructions to construct a circle with two intersecting chords that did not go through the center, and to measure one interior angle and the opposite intercepted arcs. Again they were instructed to move the points and write down the measures five times to find any possible relationships they noticed.

After students completed each task, Sarah led guided discussions using *GSP* with the SMART board. The two *GSP* tasks were of higher demand because students were expected to correctly construct, measure, and then drag to explore and create conjectures on potential relationships between arc and angle measures. There were struggles with each activity during the construction, but Sarah was able to keep the class focused even with this less-structured activity. Sarah reflected that forcing them to create and conjecture was something that she did in hopes of helping the students become more independent in their learning.

> I've been trying to use a lot of Sketchpad, hoping that with them creating, creating their own angles or creating their own triangles that, when they create them and they measure them and I ask them, "You come up with your own theorem" that they're going to take more ownership in it and it's going to be something that they basically

> can remember. In six weeks, they're going to remember that. Or, if they don't remember that, they understand how to recreate it and figure it out. So, I'm hoping that, in the long run, that they are going to become that independent learner, where they realize that they can figure this out without me telling them every little step. (Sarah, Interview 3, November, 12, 2010)

Instructional Practices.

Throughout this observation, Sarah was categorized as level 3 for Instructional Practices. Sarah was considered above level 2 since students completed high demand tasks throughout the lesson and participated in mathematical discourse both with students nearby and in whole class discussions. However, Sarah was characterized below level 4a as no activities incorporated real-world connections to the topics learned in the lesson.

Sarah began class similarly to the first two observations by having a warm-up problem that students completed. Sarah worked to include student input by asking students how they found their solution to the warm-up. Three students shared three different methods for finding the missing arc measures within the diagram. Sarah acknowledged each method, and reiterated how a method was used when asked by a student.

Unlike the previous two observations, there was not a homework review. Instead, Sarah transitioned directly into the primary class activity on relationships in circles. Sarah opened her *GSP* file to the inscribed angle page and asked students questions that led to her definition. From here, Sarah wanted students to explore relationships. Instead of providing a worksheet like she did in the second observation, Sarah stated all of her *GSP* activity directions.

Sarah: So what you are going to do is create your own central angle, your own inscribed angle. Then I want you to find the measure of the intercepted arc… I want you to do this 5 times to see if you can find a relationship with the inscribed angle.

Sarah drew a chart with five rows on the board with the column headers: central angle, inscribed angle, and intercepted arc. Sarah reviewed how to measure the angles and arcs in *GSP* and then told students to start exploring. An issue arose quickly as Sarah never provided a constructed example of the object she wanted students to create. As students began creating their circles, several created central and inscribed angles not connected to the same arc. Sarah realized this within a few minutes and regrouped the class. She demonstrated how to construct the correct angles as well as how to measure each angle. Sarah finished by telling students they could create new static diagrams if dragging was confusing them. The majority of students appeared at that point to have the correct construction and used the drag feature to complete their chart.

During this activity, students worked quietly but also talked with students nearby primarily about their observations and conjectures. One student dragged her inscribed angle's vertex around the circle and was overheard commenting to another student that the sketch seemed to break. When she stated this to the student, she had the vertex of the inscribed angle inside what was to be the intercepted arc, thus the inscribed angle was now opening to a different arc. The student later mentioned how the construction broke during the group discussion. However, instead of exploring which arc the inscribed angle was intercepting when it faced the opposite direction of the central angle, Sarah responded, "Yeah that is something with the measuring in Sketchpad. What did you notice though?" The student abandoned her concern and stated, "The inscribed angle was half the arc." Sarah then told the students to type that on their page.

Sarah followed a similar pattern for teaching interior angles. She asked students to create a second page in their *GSP* file as she moved to her page on interior angles. After reading the definition, Sarah told students to construct a circle with interior angles. Sarah expected students to construct two chords that intersected anywhere but the center of the circle. She recognized that her current interior angles went through the center, so she demonstrated how to create interior angles by using lines instead of line segments. While most students created their lines by clicking on the edge of the circle to place the two points for each line, several students clicked on the background twice to create their lines. For them, there were not points at the intersections of the lines with circle (Figure 14). When asked about this, Sarah showed her construction and stated that the points had to be at the intersection of the line and the circle.

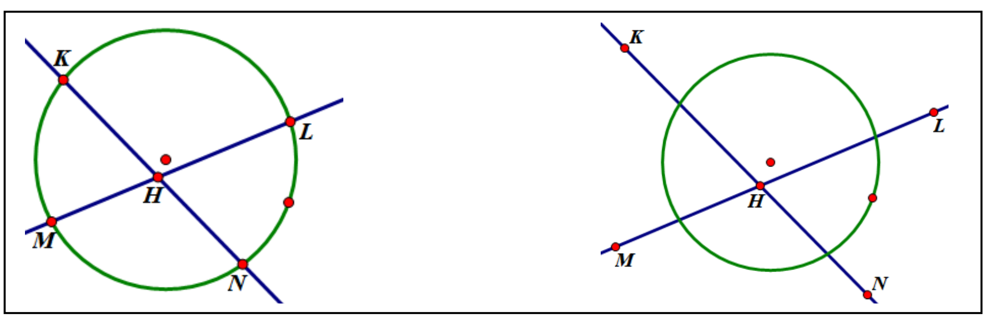


Figure 14: Example of students' correct construction and incorrect construction

Sarah had the students label their points exactly like hers and find only three measures, one interior angle and the two arcs that corresponded with that angle. Sarah again had students complete a five row chart with the column headers: arc KL, arc MN, and $\angle$MHN. While students talked more during this activity as they struggled trying to determine a relationship, much of the discourse was focused on creating conjectures. After several minutes, Sarah asked if anyone had an idea about a relationship. Multiple students said no, so Sarah provided the suggestion, “Now think about your grades in class. If I have several tests, how do I find my test grade?” Students provided a choral response, “You average them” to which Sarah responded, “That’s a hint.”

After a few more minutes, Sarah asked students for conjectures. One student stated, “The average of the two arcs is equal to the interior angle.” Sarah typed this into her *GSP* file and told her students to do the same. Another student stated, “I saw that if I added the two arcs and divided by the angle, I always got two.” Sarah replied, “That is a little different way to look at it” and moved on to reviewing the different angle relationships.

To review the angle relationships in circles, Sarah used practice problems in the students’ workbook. Sarah instructed the students to first go through the problems and write which type of angle was being used with each problem, such as central, inscribed, or interior angles. After reviewing each type, Sarah had them solve each problem. The problems were of lower demand as students were provided either arc or angle measure(s) and asked to find the other missing arc and/or angle measure(s). Sarah called on different students to provide solutions and explain how they found their solution for each problem. On two problems, students interjected that they found the solution a different way, which Sarah asked them to share. In both cases, Sarah agreed with their method, but did not explain to the students how the different solution methods were related. Sarah ended by giving students the final 10 minutes to complete homework which was similar to the practice problems. The majority of students worked on the homework until the bell rang.

Summary.

Throughout the lesson, students were engaged in completing each activity. While completing the *GSP* activities, students participated in more discussion and high demand activities than during any other part of the lesson. There were instances when Sarah's directions for the *GSP* activities caused confusion for some students. For instance, during the first activity several students did not appear to understand her original instructions and created disconnected central and inscribed angles. During the second activity, Sarah's first construction included the interior angles going through the center of the circle, and her directions had students construct an incorrect picture for explore the relationship between the sum of the intercepted arcs and the corresponding interior angle. In both cases, Sarah quickly recognized the problem and tried to address it by demonstrating how to create each object correctly to complete the activity. However, she still had to help several students individually who were confused. In her post-observation interview, Sarah recognized these issues and mentioned possibly providing the constructions to limit these problems in teaching this lesson another semester.

> I don't know if I should have had the drawing ready for them. Maybe that would have made it easier because I kind of had to go back and show them what I wanted

them to do exactly because it was easier if they had the same arc. You know, they were going through the same arc. And I realized that once I was walking around the room, “Oh, they’ve got it drawn wrong. They may not see the connection as much.” So, that may be something that I want to try next time. The interior angle, I thought, would be hard, you know. But then, once I said that about the grades the light bulb went off. (Sarah, Interview 3, November 12, 2010)

While there were opportunities that could have been exploited for additional whole class discussion, Sarah attempted to serve primarily as the facilitator of learning and discussion. Sarah was also quick to recognize when there was confusion and when students needed additional scaffolding to explore the constructions. In this regard, Sarah worked to maintain high cognitive demand in learner-centered activities using *GSP*.

Observation 4.

Technology Integration.

During the final observation, Sarah taught the transformations of reflections and rotations with an emphasis on providing the graphical, algebraic, and matrix representation of each transformation. Sarah was characterized as level 2 for Technology Integration of this lesson. Sarah was considered above level 1 as students used *GSP* throughout the lesson. However, Sarah was categorized below level 3 since students were often guided through *GSP* activities instead being provided opportunities to explore and conjecture about mathematical relationships.

In using *GSP*, Sarah created a five page file. The first page had two points, A and B. A was constructed to stay on the x-axis. B was constructed as a reflection of A over the line y = x. The second page had a sketched right triangle with points A(2, 1), B(2, 6) , and C (4, 1). Pages three through five were blank. No instructions were provided on the file. Instead, Sarah gave each student a fill-in-the-blank notes packet for the transformations unit. Sarah used *GSP* to demonstrate each concept in the notes and led guided discussion throughout the sections on the two transformations.

Instructional Practices.

During this lesson, Sarah was categorized as level 2 for Instructional Practices. While Sarah was considered above level 1 because she did not lecture the entire class, she was characterized below level 3 as she led much of the instruction and demonstration for each activity during the lesson. However, the cognitive demand of the lesson was mixed as Sarah typically asked quick low demand questions, but the lesson was often of higher demand as students were continually working to make connections between the three representations of each transformation.

Unlike previous observations, Sarah started class by having students download the *GSP* file while she handed out the notes worksheet. Sarah began the lesson by teaching reflection over four different lines: x = 0, y = 0, y = x, and y = -x. With each reflection, Sarah would show how to mark the line of reflection and how to reflect points A and B. Students would then be given a few minutes to explore what happened to the coordinates with each reflection. Sarah would then ask students where the new points were located, and lead students to formulate the matrix and algebraic representation using the coordinates of the image and pre-image.

Sarah did not use *GSP*'s graphing function to create the lines of reflection for y = x or y = -x. Instead Sarah showed students how to create the line using the line tool. She first reminded students to make sure that "Snap Points" was on. She then suggested putting the first point for the line at the origin and the second point at (1,1) for y = x and at (-1, 1) for y = -x.

Sarah followed a similar pattern when teaching rotations of 90°, 180°, and 270°. Sarah used the same page with the same two points to explore how each rotation changed the values of the ordered pair. First, she began by showing how to mark the origin as the center of rotation. After performing each rotation, Sarah provided time for students to explore the image and pre-image before leading discussion on the creation of the matrix and algebraic representation for the given rotation.

After creating the matrix and algebraic representations for the given reflections and rotations, Sarah asked students to move to the second page of the *GSP* file which included the triangle on the coordinate plane. On this page, Sarah had students perform two separate transformations to the triangle: x-axis reflection and a 270° rotation. Sarah began by demonstrating how to reflect the entire triangle and label the points of the image triangle. Sarah reminded students that the x-axis algebraic representation was $(x,y) \rightarrow (x, -y)$. Sarah then explained while writing on the whiteboard how to determine the matrix which represented the triangle and the multiplication matrix to perform the x-axis reflection. Sarah finished the *GSP* lesson by having students create the 270° rotation of the triangle and provide the algebraic and matrix representations. Students worked throughout the allotted time with several of them discussing their observations. Sarah finished by calling on students to explain how to determine each representation.

Throughout the lesson, students were relatively limited in their opportunities for individual exploration and student-to-student discourse. However, the majority of students were attentive during each activity, completed each transformation on their own file that Sarah demonstrated, and worked quietly when provided time to consider how to create each representation of a particular transformation. Several students did talk with students nearby when given opportunities to determine the representations, and the majority of their discourse was on-task. When provided time at the end of class, students worked quietly and attentively on their homework.

Summary.

Throughout this observation, Sarah was characterized at level 2 for Technology Integration and Instructional Practices. Although the activities in the lesson provided opportunities to make connections between multiple representations, Sarah often demonstrated first and had students explore afterward as reinforcement. This was the opposite of previous observations in which Sarah would first have students explore topics and then use group discussion to reinforce their conjectures. While students were not given as much opportunity to individually discover, they remained engaged throughout, possibly because the cognitive demand of the activities was still high in trying to understand the multiple representations of each transformation. Making the connections was the primary reason Sarah decided to use *GSP* to demonstrate the transformations.

> I tried to plan a lesson where it would be a visual aid for them to see the reflection and the rotations… I thought it would be easier for them to actually see the movement that occurs when you reflect across different things and rotate, you know, different ways, at different angles. We did everything visually first and then I asked them to try to do it without it but, if needed, they could use Sketchpad to remind themselves, and some of them did. (Sarah, Interview 4, January 4, 2011)

Influence of the Professional Development.

Sarah suggested throughout the semester that she felt the professional development opportunities had an influence on her use of *GSP* in teaching her classes. For instance, Sarah felt the professional development continued to provide her with new skills to adequately use *GSP* in her class. In her second interview, Sarah stated, "It [the professional development] has helped me to figure out how to construct certain things an easier way. Anything that I've heard from the professional development online or this summer, I've tried to look back. I've used those things (Sarah, Interview 2, October 21, 2010)." Additionally, in the third interview Sarah noted that she was adding hide/show and other action buttons to her files after learning about them in the online professional development.

Sarah also suggested that the continuous professional development had been a positive reinforcement for her continued use of *GSP* in classroom activities. "By going to the Summer Institute and doing the staff development online, it has kind of kept me going with it. I think that if I had just stopped [with the Summer Institute], I would have forgot things (Sarah, Interview 4, January 4, 2011)." Additionally, *GSP* gave her a desire to teach topics in a new way, which had led to positive results. As Sarah stated:

The Summer Institute really helped her feel like I can use Sketchpad. Those items I don't know, I am now willing to figure it out. [Also,] I really feel Sketchpad has really helped my students grasp concepts and think for themselves better. And they seem to enjoy it! (Sarah, Interview 3, November, 12, 2010)

Characterization of Sarah throughout the Semester.

Throughout the semester, Sarah worked to incorporate *GSP* into her lessons (Figure 15 and Figure 16). Sarah used the entire semester to learn, adapt, and improve. In each interview, Sarah reflected that she was still working on trying to determine timing for completing activities when using *GSP*. She stated early on, "I'm really trying to implement Sketchpad this year. I'm not used to this. I'm not used to how much time it's going to take them" (Sarah, Interview 1, September, 17, 2011).

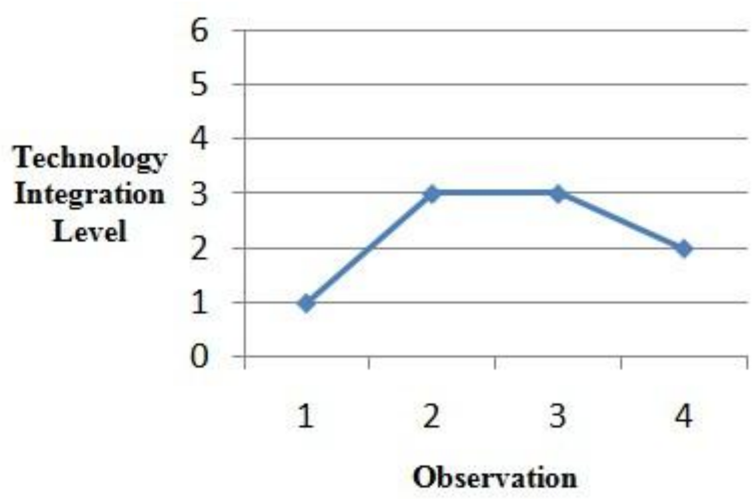


Figure 15: Sarah's characterization of Technology Integration through the Four Observations

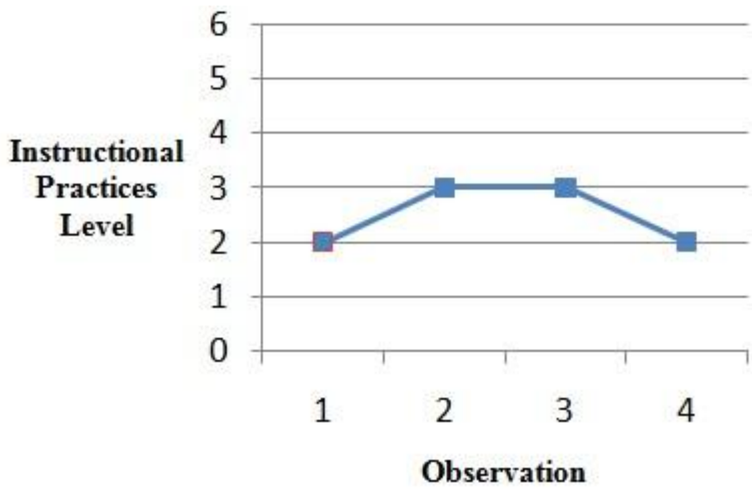


Figure 16: Sarah's characterization of Instructional Practices through the Four Observations

Sarah continued to work on determining how much structure and guidance she would provide within her *GSP* activities. In the second observation, Sarah provided a *GSP* file, a Word document with two charts to be filled out, and verbal instructions on the activity with much success. However, when Sarah tried following a similar structure in the third observation by providing a *GSP* file and verbal instructions, students struggled and became confused. Sarah was quick to recognize that the students were struggling and provided additional help that moved them forward while maintaining the integrity of the activity. Additionally, her classroom management skills helped her keep the students on-task even when they were given less structured activities or were confused about how to complete an activity within *GSP*.

Sarah also recognized that *GSP* was aiding her students, which was why she continued using the program throughout the semester.

> I think that it has really helped my visual learner. Where, before, I would try to do things visually by using models and things, but this allows them really to play and fool around with it and really be able to look at it in different ways. (Sarah, Interview 4, January 4, 2011)

Sarah continued throughout the semester to increase her use of teaching with *GSP* whenever possible, which in turn got her students interested in using *GSP* for their personal use. For instance, Sarah stated during her third interview:

> What I've done so far is, all of the circle lessons are on Sketchpad. They're uploaded on my Wikispace. So they can go and get those lessons if they need more practice. Some of them were creating their own [files] and writing notes in [them], which I really like. (Sarah, Interview 3, November 12, 2010)

Since she could see how much *GSP* supported her students in learning geometric concepts, Sarah stated that she wanted to continue improving in creating and learning how to better incorporate *GSP* into her lessons. "I just want to, you know, continue to learn different ways to implement it and find ways that would make it easier for students to see and understand the topics" (Sarah, Interview 4, January 4, 2011). It is with this attitude and willingness to improve that made Sarah show progress throughout the semester on her Technology Integration and Instructional Practices.

Case 4: Sean

Sean was a case of an experienced teacher both in teaching and in use of technology for teaching. During the observed semester, Sean was beginning his twelfth year teaching and seventh year teaching Geometry. Sean received his teaching license as part of his undergraduate degree. All observations took place during Sean's first period standard Geometry class. The class averaged 18 students. There were 11 male and 7 female students.

The arrangement of Sean's classroom remained the same during all four observations. Students sat in rows facing the front of the classroom. Across the front wall were three whiteboards. At the front right of the room, Sean had a mobile cart with a projector and his laptop computer. On the floor, he also had an overhead projector which he would place on a desk when needed. At the front left of the room, Sean had a podium. The right wall and back wall included additional white boards that were not used during the observations. Posters of mathematical topics and mathematical applications were displayed on the walls. Sean's desk was in the back left of the room. However, he never sat at his desk during any observation as he was constantly circulating throughout the room.

Sean considered himself proficient with *GSP* as he had taken three graduate-level courses prior to the Summer Institute that had incorporated *GSP* into activities and projects. Additionally, Sean had used *GSP* with his honors students for several years. "I've had Sketchpad in the classroom where I've been very successful in honors classes in incorporating Sketchpad from anything from long-term projects to just a fifteen minute 'Explore this. Hey, let's talk'" (Sean, Interview 4, December 9, 2010). In contrast Sean stated, "I used it mostly for demos" (Sean, Email, February, 23, 2011) when teaching standard Geometry in previous years. During the observed semester Sean felt his standard Geometry students needed to do more than watch him perform demonstrations, so he worked to create student-based interactive *GSP* activities. Sean stated in his final interview, "I've made a very concerted effort this semester to incorporate a lot more in that level class" (Sean, Interview 4, December 9, 2011). With Sean's understanding of *GSP*, his experience in teaching Geometry, and his determination to utilize *GSP* with his non-honors students, positive improvements were noticed in his levels of Technology Integration and Instructional Practices for his standard Geometry class.

Observation 1.

Technology Integration.

Sean taught his students about inductive reasoning and conjecture during his first observation. For this lesson, Sean was characterized as level 3 in Technology Integration. Sean was considered above level 2 as students completed high demand activities using *GSP*, but he was categorized below level 4a as no real-world activities were incorporated into the lesson. While Sean integrated opportunities to learn both with and without technology, his use of *GSP* required students to use the program's full capabilities in a way that was accessible for new users. This included requiring students to measure segments and angles, drag objects to explore potential relationships, and compare measurements through dragging and using animation buttons.

Sean created eight pages within this *GSP* file. Each page had a preconstructed object, instructions on what to measure, drag, or animate, and a focused question about which students were to create a conjecture. The pages guided students to: recognize B was the midpoint of a segment; identify the given triangle as equilateral; recognize $\angle 1$ and $\angle 2$ as a linear pair; identify the given triangle as right; determine whether or not a given quadrilateral was a square; recognize two angles as vertical; recognize a point on a line of reflection is equidistant from the reflected object and its pre-image; and discover that the measure of the midsegment of a triangle is half the length of the measure of the third side (Figure 17).

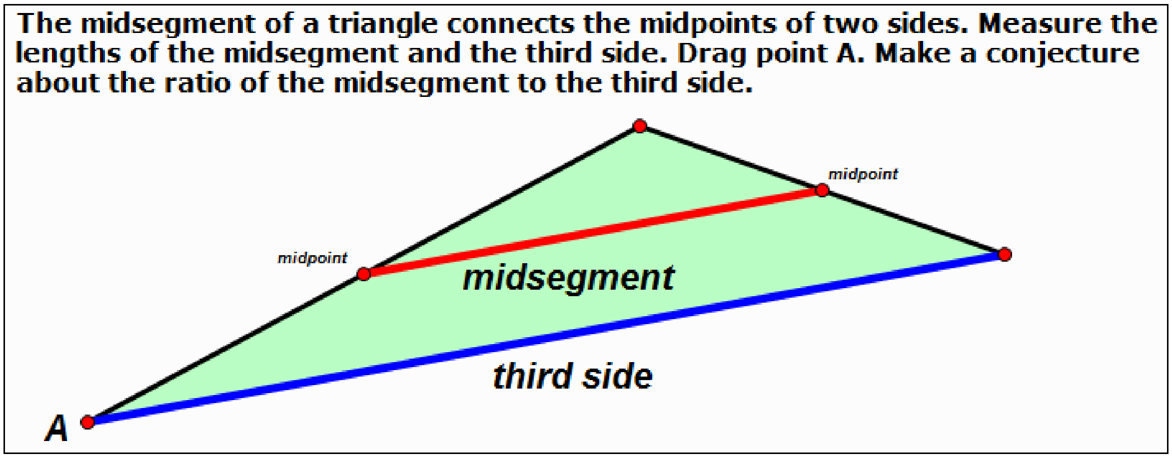


Figure 17: Page 8 of Sean's GSP file on creating conjectures

While Sean led discussions through the first four pages of the file, students were left to explore the final four pages with a partner. The final four tasks were of higher cognitive demand than the first four pages as well as only the concept of vertical angles had been taught prior to this observation. With this lesson, Sean provided students with an opportunity to become more comfortable with *GSP* while keeping the emphasis on mathematical learning.

After the observation, Sean stated that one of the reasons he incorporated *GSP* with this type of activity was to help build confidence in his students' ability to share their conjectures and solutions.

> In this class, you see a lot of reluctance [to share]. I think the reluctance to give an answer and to stick your neck out a little bit and try and support your own answer is

> because of the confidence issue. So, to give them, you know, I tried to give them some things on the computer where they could do some investigating, learn some things, measure some things, get some information. Trying to back up their own thinking about, "Yeah, I think this is going to be true or false." You know, that all plays into that confidence issue. So, I think that's got to be the biggest thing as part of this lesson or working with this class. (Sean, Interview 1, September 20, 2010)

From early on in the semester, Sean recognized *GSP* as a tool for teaching and learning geometrical topics. In this lesson, he utilized *GSP* to offer students an opportunity to explore and create their own understanding. In doing so, he maintained activities with high cognitive demand while integrating *GSP* in a way that made learning through a new program possible.

Instructional Practices.

During the first observation, Sean was categorized as level 3 for Instructional Practices. Sean was considered above level 2 because throughout the lesson, Sean used a variety of instructional methods, incorporated student practice both individually and with a partner, included activities that had problems with varying levels of cognitive demand, and guided students in sharing their conjectures and justifications during group discussions. However, Sean was considered below level 4a as no real-world activities were included in the lesson.

Sean began class by reviewing the homework assignment, which had students explain what they observed in five optical illusion pictures and why geometrical properties were distorted in four other pictures. Sean asked students for their solutions to some of the problems and provided solutions for others. When a solution was provided, Sean would also ask the student to explain his/her reasoning.

Sean transitioned to a 30-minute session of direct-instruction with individual practice to begin the lesson on inductive reasoning. In the lecture portion of the direct-instruction, Sean shared a personal story of how an EMT used inductive reasoning to determine whether he had sustained a possible concussion after taking a major hit playing hockey. Sean also asked students to share what they thought terms like conjecture, plausible prediction, and counter-example meant. To reinforce what students learned about inductive reasoning, Sean asked students to complete seven problems from the textbook. These problems were of moderate cognitive demand as they had students predict the next object in geometric patterns or the next number in a numerical sequence. Most students worked quietly and remained on-task. As they finished the problems, several students checked their answers with students nearby while others talked quietly about other topics.

To review the problems, Sean called on different students to provide their solutions. For the first two problems, Sean had students come to the board and provide their work and solution while others finished the practice. For the rest of the problems, Sean had students explain their solutions while he drew the picture or wrote the solution on the board. If a student did not explain how he/she solved the problem, Sean would ask guiding questions to elicit their thinking.

Once Sean finished the inductive reasoning practice, he transitioned the class to the *GSP* activity. Students were asked find a partner and share a computer to explore the *GSP* file. Sean then led whole class discussion through the first four pages of the file. Instead of demonstrating while leading discussion, Sean asked a student to project his computer screen. While Sean would remind students how to find the needed measurements or calculations or to use the drag feature on each page, the student would try to demonstrate what Sean was saying. For example, the following discussion occurred while exploring the first page of the *GSP* file.

Sean: So we are going to work through some of these together, and others you are going to do on your own. So Student 1 is going to help us out on the computer (Student 1's computer is projecting). The directions say to measures segment AB and BC, drag C, and make a conjecture about B. So we measure by clicking on the two points and then go "Measure" → "Distance". Student 1, let's start with segment AB. Click on A and B. Make sure only they are highlighted. Now click "Measure" → "Distance". Can you click and drag that measure to the bottom corner? Now let's do that for segment BC. Click on B and C. Make sure only they are highlighted. Now click "Measure" → "Distance". Can you drag that measure to the bottom corner as well? Student 1, now drag the segment. What do you notice?

Student 2: They stay the same.

Sean: Good, so what is a conjecture you could make about this segment?

Student 2: B is the midpoint.

Sean: Good, so if you click on the "A" on the left side, that is our text box. Now write your conjecture, "B is the midpoint of segment AC."

Throughout the first four pages, Sean continued to emphasize measuring and dragging. He reiterated these features before allowing students to work with their partner on the final four pages in the file. While working independently on the final four pages, not all students worked with a partner. Three pairs worked individually and then would talk with each other to agree upon their conjecture. One pair worked completely together, but this occurred primarily because one partner's computer was not working. The other 12 students worked quietly and individually. Most students stayed on-task and completed pages 5 – 8. As students worked, Sean circulated through the class, answering questions and helping students with any issues they had in using *GSP*.

In reviewing the final four pages, the same student projected his file along with his conjectures. Sean used his conjecture on each page as a starting point for discussion. On each page, Sean would ask the student to drag or animate while he explained why the conjecture was correct or needed revising. Sean placed an emphasis on dragging with page 5, which stated, "Alan's conjecture about the figure below is 'Quadrilateral ABCD is a square'. What do you think?" Several students, including the student projecting agreed that ABCD was a square. After asking students whether they dragged every point and not getting a response, Sean asked the students do so.

Sean: Student 1, take B and drag it up and down (Student 1 drags B, creating a rectangle)…Now, where it is, is this a square?

Student 1: No.

Sean: No, we now have a rectangle. If we are after a true conjecture, then we have to say it is not a square. Remember, the dragging will help us with this.

To finish class, Sean put a problem on the board that stated the given information as $\overline{FG} \approx \overline{GH}$ and the conjecture as "G is the midpoint of $\overline{FH}$". Sean reiterated that the given information is automatically true, "That is fact. You can't break that fact." However, he stated the conjecture had to be tested, and to be a true conjecture, it must always be true. Sean then provided students several minutes to work on the problem and see whether they could determine if it was a true conjecture or if there might be a counter-example to show it was not always true. Sean led discussion, but he tried to do so without giving away the counter-example. He first asked how many thought it was true. About half the students raised their hands. Sean drew $\overline{FH}$ with G as the midpoint and asked if that was sufficient. One student thought it was not and suggested making two congruent segments that were not connected. Sean drew this on the board and acknowledged it as a good idea. "Now I like that, but aren't these G's the same? So they have to be linked somehow." Another student recommended drawing the picture as an angle with G being the vertex. Sean drew this on the board as well and agreed that this was a good counter-example since the G's were now connected and the segments were of equal length. Sean finished class by assigning homework and stating that they must include pictures in the homework to determine whether each statement was true or false.

Summary.

Throughout this lesson, Sean was categorized as level 3 for Technology Integration and Instructional Practices as he worked to use *GSP* to explore conjectures of mathematical objects. More importantly, he made topics that were not yet learned accessible for students to create conjectures. Sean reflected afterward:

> I decided my main focus for the lesson would be a Sketchpad thing. I was trying to do two things with that: one was getting them to think geometrically about the idea of conjecture and evaluate some specific sketches… I also wanted to give them some more experience with Sketchpad which I hadn't really given... So even in terms of measuring angles and measuring segments, they hadn't done a whole lot of that just on their own. So, I just wanted to introduce the concept of making conjectures together with some simple calculations. (Sean, Interview 1, September 20, 2010)

While Sean led discussions throughout the lesson, he did so in a way that worked to elicit student thought and understanding. He tried to limit stating facts and instead worked to use student suggestions and explanations. Additionally, several times Sean had students restate their thoughts using mathematical terminology. For instance, this occurred when reviewing page 6 on the *GSP* file.

Sean: So number 6, what do you notice?

Student: They are the same.

Sean: Good. Now let's try to improve our terminology. What is the relationship between those two angles?

Student: They are vertical.

Sean: Good. So let's change that in our text box so that we are stating the type of angles they are.

Sean still felt his lesson could be improved. Sean recognized that the task on the fifth *GSP* page that asked students to analyze another student's conjecture caused students problems. However, he thought that task had been one of the most valuable in the *GSP* activity and wished he had included more like it.

> When we got to the one about the square, I had tons of people say, "Oh, yeah, it's a square" when once you drug around the vertex it clearly wasn't a square. So, they get the idea of "Could it be a square?" versus "Is it a square?" confused. The idea of is it a square means is it all the time a square. So, that leads you into that idea of counterexample. I wouldn't change a whole lot other than maybe alter – like I said the sketch where I think the idea of "Hey, here's a sketch. Here's somebody else's conjecture. You move the sketch around and tell me if you agree with this person or not." I think that's a powerful thing at the beginning of this idea and maybe to have an extra problem like that. (Sean, Interview 1, September, 20, 2010)

Sean's focus and reflection on the details of his lessons and activities continued throughout the course of the semester as he worked to increase the number of *GSP* activities his standard Geometry class completed.

Observation 2.

Technology Integration.

During the second observation, Sean provided students an opportunity to complete various activities on different topics. Sean included a worksheet to explore distance between a line and point, a worksheet to review for their upcoming test on relationships in parallel and perpendicular lines, a *GSP* project that explored symmetry and rotation, and a *GSP* activity that was an introduction to the upcoming chapter on triangles. With the incorporation of the *GSP* activities he created, Sean was characterized as level 3 for Technology Integration. Sean was considered above level 2 because the *GSP* activities were of high cognitive demand. These activities did use images of real-world images. However, students were not solving real-world problems with these activities; they were exploring the geometry of the images. For this reason, Sean was categorized below level 4a.

With the two *GSP* activities, Sean continued to have students utilize a variety of tools in *GSP* while also keeping the focus on attaining understanding of mathematical concepts. The first activity was the Symmetry and Rotation Project, which was a first six weeks project that was due the day of the observation. Since several students had connectivity issues at home, Sean allowed them to complete the project in class. The file itself included three pages with three different pictures: the Mitsubishi Automobile log, a Pennsylvania Dutch hex symbol, and the Philippines national flag (Figure 18). On the first page of the file was a link to a Google Form and instructions to use the three pictures to answer questions within the Form. The Form included 10 multiple-choice questions. While students could guess a solution and were not required to provide any justification to their answers, the questions were of moderate to high cognitive demand. The questions asked students to determine different angle measures within a picture, the angle of rotation among identical objects in a picture, and lines of reflection within each picture. For example, one question with the Mitsubishi symbol asked:

What is the smallest angle of rotation so that one red quadrilateral rotates onto another one?

- 60 degrees
- 90 degrees
- 120 degrees
- 150 degrees

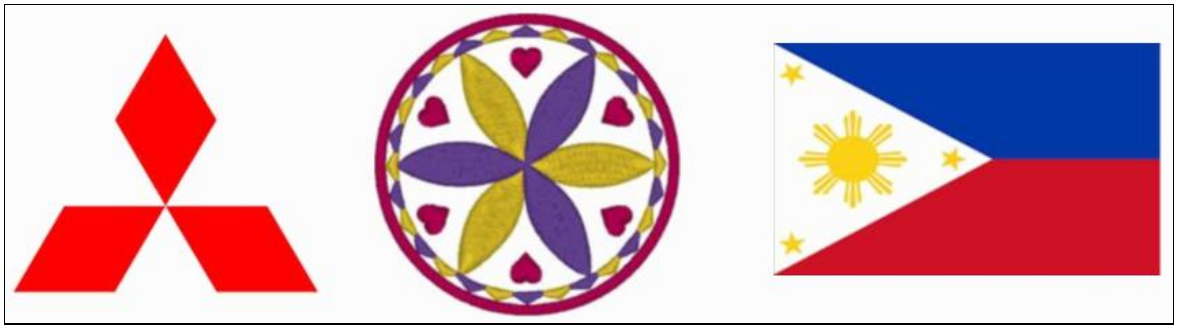


Figure 18: Symbols used in Sean's Symmetry and Rotation *GSP* file

The need to provide multiple activities came from several students' limited access to the internet at home to complete the Google Form in the Symmetry and Rotation Project.

> I downloaded some images from the web and I asked them 10 questions about the three different images… It all linked to a Google Doc, which actually created a little bit of a problem I didn't realize which was that these kids go home and they don't have internet access. They're trying to answer this, they can't link to the Google doc even though the Sketchpad file might be sitting on their computer already... I needed something for the other students to be doing when half the class had already done

> this. So, then I put together a little file on triangles, which is previewing what's coming up tomorrow after the test. (Sean, Interview 2, October 7, 2010)

Students began the second *GSP* activity once they completed the test review and *GSP* Symmetry and Rotations Project. Students continued this file the following day once they completed their test. The file included five pages with tasks of varying levels of demand. The first page included questions that asked students to create an obtuse and an acute triangle. The second and third page had students construct an isosceles and equilateral triangle, respectively, using circles. The fourth page included questions that asked students to construct an isosceles triangle using a different method. The final page included questions that asked students to find each type of triangle they had just created in a picture of a mosaic from the San Marco Cathedral in Venice, Italy. The constructions of the isosceles and equilateral triangles required students to not only understand the properties of each triangle, but also recognize how specific properties could be constructed so that their triangles would pass the drag test in *GSP*.

Sean reflected afterward about how the connectivity issues influenced his lessons and technology integration. When asked, "Do most of your students have internet at home?," Sean responded:

> I think we're right around 50%. Maybe a little bit over… My intent is not to design things to put people at a disadvantage. I know it's not 100%, so it's sort of, ultimately, you build it in your lesson plans. We can't just say, "Hey, go to this website. Download this" because they're not going to be able to do it. But that's the great thing about Sketchpad, because we have individual copies on the computer, if

> we at least download [the files] in class. It's on their computer. They've got no excuses then. (Sean, Interview 2, October 7, 2010)

Instructional Practices.

Throughout this lesson, Sean was categorized as level 3 in Instructional Practices. Sean was characterized above level 2 because students were provided opportunities to collaborate and complete high demand activities. Sean was considered below level 4a because although several activities used real-world images to answer geometry questions, no activity focused on solving a real-world problem.

Sean began the lesson with a low demand task around finding the distance from a point to a line. In this activity, Sean provided students with a ruler and a worksheet that required them to create a segment that represented the distance from a given vertex of an object to one of its sides. Sean demonstrated how to draw the segment representing distance by completing the first problem using his overhead projector. Afterward, students worked quietly and attentively to complete the activity. Even though this was a difficult task for many of the students, there was no connection for why they were completing this worksheet other than the fact that distance between a point and a line is found using a perpendicular segment between the two objects. Sean reflected afterwards that he disliked doing the activity, but he let the textbook override his thoughts on placement.

> I hate doing that. It's boring to draw perpendicular line after perpendicular line… There's no context to it until we get to chapter 5, when we get to triangle centers. Then there's a huge amount of context to it. So the book in some sense has let us down in that "Wow, it's right there at the end of the chapter. Let's just do it. We'll

do it all." My test has it on, the whole deal. Could it be put in a better place in the curriculum? Yeah, probably. Why didn't I do that? Probably, I don't know, you just get caught in, you're like "let's just do it and roll." (Sean, Interview 2, October 7, 2010)

Once students completed the worksheet, Sean handed out the test review and had students work on it for twenty minutes. Unlike the first observation, most students moved and worked with a partner to complete the review. Most partners worked actively on completing the sheet while Sean circulated answering questions. Questions on the review included multiple levels of demand, ranging from questions that asked students to find the slope of the line that included two given points to finding missing values of x and y that required using multiple relationships of parallel and perpendicular lines.

For the final 40 minutes of class, Sean had students complete one of the two *GSP* activities. Most students continued working with the same partner. They remained engaged and on-task as they completed each activity. Additionally, students were responsible for determining what they needed to be doing throughout the allotted time. While students worked, Sean walked around the class helping students with questions. For instance, one group asked Sean why their rotation was not working correctly. Sean helped them determine their center of rotation and mark it for rotation in *GSP*. With another group, Sean realized they had created only a sketch of an isosceles triangle. Sean explained the difference between sketches and constructions in *GSP*, and he helped guide them in the right direction without removing their discovery of how to construct the triangle. As class ended, Sean reminded students to submit their Similarity and Rotation Project, complete the test review for homework, and save any work completed on the triangle file.

After class, Sean remarked how impressed he was with the discussion he had with students and how well students interacted on each of the various activities.

> I think the best thing that came out of today was I had lots of unique interactions with students… They're sort of, they're adding value when they're together. It is. I mean, I saw that today, so that was one of the most obvious things that came about. I mean, I'd even make a list of nine different interactions that I had with at least one or two students that were maybe working together on something that I thought were very valuable and I, I can individually remember those things and so I know that there was value that was there. (Sean, Interview 2, October 7, 2010)

Summary.

Throughout this lesson, Sean was characterized as level 3 for Technology Integration and Instructional Practices. While not all activities were of high cognitive demand, Sean integrated activities that had students explore geometric concepts in real world objects. As Sean stated, "I think the trick of it is, can you get in the mathematics and then can you structure it so that there's enough variety, enough interest, enough this, enough that" (Sean, Interview 2, October 7, 2010). With this lesson, Sean was able to successfully do so. Sean served as the facilitator, answered questions, and help students think through problems that confused them. Throughout the lesson, students were engaged and on-task. Most worked together and were sharing ideas as they completed each problem.

The only concern Sean had from the lesson was that students who were not able to complete their Google Form in class may have lost their solutions.

> I'm afraid that some people got through eight of them, and I don't know what happens then. I don't know if when they walk to their next class, it wipes out all the answers and they have to start again or whether it submits the eight and now two questions aren't answered. (Sean, Interview 2, October 7, 2010)

Even with this uncertainty, Sean provided a lesson with high student involvement during this observation. Students were actively engaged, and most were collaborating with a partner. Students were expected to complete high demand tasks. Sean stated, "The students did a really nice job of helping each out and working with each other" (Sean, Interview 2, October 7, 2010). This was possible due to Sean's classroom management skills and structured activities, as he created an environment where they could successfully work well together.

Observation 3.

Technology Integration.

During the third observation, Sean taught a lesson to his students on how to simplify radicals and find the lengths of segments in right triangles with the altitude from the right angle using geometric mean. For this lesson, Sean was characterized as level 1 for Technology Integration as the only use of technology was Sean performing a demonstration with *GSP* to introduce the idea of geometric mean relationships in a right triangle with an altitude. Sean demonstrated for his students how to construct a right triangle and the altitude from the right angle in *GSP*. He emphasized all the features that were hidden that made the construction possible. Finally he labeled and measured the altitude and the two segments made by splitting the hypotenuse where the altitude intersected. Sean showed through *GSP*'s calculation feature that the square root of the product of the measures of the two segments was equal to the measure of the altitude. He completed his use of *GSP* by stating that their goal during the lesson was to learn why that was true.

While Sean was categorized at level 1 since he did not provide opportunities for student exploration with *GSP*, he did put thought into what would work best for his students in understanding this complex topic. During the interview, Sean stated that there were several reasons he limited his use of *GSP*.

> There's usually some type of exploration [in my lesson]. That was the thing that was a little different yesterday. I just demoed something. And I sort of had two reasons for doing that. One, the sketch isn't – the sketch would be a little time consuming for them... So, it was more me saying, "…Watch me make this. Know that there are really perpendicular lines, parallel lines, a circle," you know whatever, in the background and I thought I accomplished the goal which is to get them thinking a little bit about, "Okay, how would I make a sketch with things in the background and hiding things." They don't really watch me make a whole lot of sketches, so that was kind of a nice offshoot of that. (Sean, Interview 3, November 18, 2010)

Sean also stated, "I didn't really have a sense that visually watching triangles move on the computer screen was going to be a lot of value added. I might rethink that" (Sean, Interview 3, November 18, 2010). Sean felt that his students would get the most out of manipulating the physical paper triangles on their desk to understand the relationships within the right triangle with an altitude. As had been observed prior, Sean's emphasis for this lesson was on providing the best learning opportunities for his students, whether or not that included technology.

Instructional Practices.

While Sean had limited use of technology within this lesson, his Instructional Practices was characterized as level 3. Although Sean used considerably more lecture and demonstration throughout this lesson than prior observations, he was considered above level 2 because students were still provided opportunities to complete paper-based tasks of higher cognitive demand. Although Sean provided a significant amount of teacher-directed instruction, his activities were structured to help students build connections between how the concept of geometric mean could help solve problems that involved a right triangle with an altitude from the right angle through similar triangles. Sean was considered below level 4a as no activity included real-world applications.

Sean started his lesson with a short lecture on solving non-perfect square roots using a factor tree. Sean began with $\sqrt{(104)}$. Sean called on a student to help him create the factor tree for 104. Sean then explained how to determine what values went on the outside of the radical and which went back into the radical. Afterward, he had students check $\sqrt{(104)}$ and $2\sqrt{(26)}$ on the calculator to recognize that simplification of a square root still provides same value as the original square root.

Sean then gave every student a worksheet with twelve problems. The worksheet included three sections that coincided with how Sean split the lesson. The worksheet was of moderate cognitive demand as understanding of the prior section was needed to complete the following section. For example, the first section had students find the exact value of six non-perfect square roots. The second section had students find the geometric mean between two numbers for four different pairs. The final two problems had students find two missing segment lengths in a right triangle with an altitude from the right angle.

Sean had the students complete the first problem on the worksheet as a group, which was simplifying the square root of 32. As different students explained how to create the factor tree, Sean drew the tree on the board. Eventually Sean wrote $\sqrt{(2\cdot2\cdot2\cdot2\cdot2)}$. When asked what to do next, one student suggested:

Student 1: You have $2^2\sqrt{(2)}$.

Sean: (writes student solution on the board) Alright, how did you get that?

Student: There are two pairs of twos. That makes 2^2 on the outside.

Sean: That's right. So instead of writing 2^2, let's just write 4 since $2^2 = 4$ (erases 2^2 and writes $4\sqrt{(2)}$).

Sean had students complete the five additional radical simplification problems. Students worked quietly and attentively. As students worked, Sean circulated and answered questions. When reviewing, Sean showed the solutions using the overhead projector. No questions were asked by the students.

Next, Sean transitioned to the *GSP* demonstration. He told the class that he decided a demonstration would work better today. He then demonstrated how to construct the right triangle and altitude, leaving all of the objects used in the construction visible. Once the entire object was constructed, Sean hid all the extraneous objects in the construction and stated, "As you can see, there is a lot going on in the background that is not seen. The files you have been working with this semester have been similar to that." Sean then labeled the two segments of the hypotenuse split by the altitude in the right triangle as *a* and *b*, and the altitude as *x*. He measured all three segments and then told students he was going to do something odd, which was to multiply the measures of *a* and *b* and then take the square root of the product. Students quickly stated that the calculation was equal to the measure of *x*. Sean stated that their next goal was to determine why that happened.

Sean used this as a lead-in to the guided exploration with paper triangles. Sean gave students scissors and a paper that included two congruent right triangles with the altitude drawn from the right angle. Students were instructed to cut both large triangles out. After that was completed, Sean told the students to pick up one triangle and cut along the altitude. Sean asked the students to examine their three triangles and determine if there was anything special about the triangles. Students rotated the triangles and started laying one on top of the other. After a few minutes, Sean asked if they found anything. One student stated that the triangles were similar. Sean replied that that conjecture sounded plausible. He stated that all three triangles already had one congruent angle, the right angle. He asked which other angle would provide AA similarity. Another student replied he lined up the top ones. Sean then asked the students to line up their triangles and had them place the corners together one at a time to see that the three triangles were all similar using AA similarity. Sean then told the students to trace the three triangles on their paper and label each triangle with the sides *a*, *b*, and *x* that were labeled on the right triangle construction from the *GSP* demonstration. Sean walked around as students worked on labeling the sides. He recommended physically reflecting or rotating each triangle as needed to determine where each label was needed.

After the students had the sides correctly labeled, Sean stated that since the triangles were similar, they could use proportions to help find the lengths of each segment. He asked if they noticed any proportion with the three labeled parts. Several students stated the proportion x divided by b equaled a divided by x. Sean agreed and worked out the problem by cross multiplying and taking the square root of both sides. He finished by writing $x = \sqrt{(ab)}$ and stated that was the same as what was found in the *GSP* demonstration.

Sean transitioned a final time to a brief lecture with notes and practice on geometric mean. Sean wrote all of his notes on the board, provided definitions and examples for geometric mean, and also suggested that students check their work by verifying that the fractions on each side of the equal sign were equivalent. Sean first had students complete and review the four geometric mean problems on the worksheet before moving to the final two triangle problems. For the final two, Sean told students he expected them to use their paper triangles, draw all three triangles on their paper, label all the necessary sides, and provide their proportions. Again, Sean circulated while students worked quietly. He helped individual students figure out how to correctly rotate or reflect their triangles and answer other questions about their proportions. To review, Sean drew the three triangles on the board for problem 11 and asked students to help him go through how to solve the problem. As students gave him instructions accompanied with justification, Sean labeled his picture, created the proportion, and used a factor tree to simplify each solution. For problem 12, Sean asked one student to draw his triangles on the board and another student to write his proportions. Sean provided the last five minutes for students to complete the homework which included both finding the geometric mean of a pair of numbers and finding the missing values in a right triangle with an altitude from the right angle.

Summary.

This lesson included more direct instruction from Sean and less student interactions than previous observations. However, students were still given opportunities to explore high demand problems and make connections as to why geometric mean was used to solve these problems. As Sean reflected, "Everything was based around that idea of geometric mean. At the same time, I was trying to deemphasize the word a little bit and actually stick with the idea of similar triangles" (Sean, Interview 3, November 18, 2010). This was one of the reasons why Sean provided students with the paper triangles and continually worked to make them use the triangles to create the correct proportions.

Even though Sean did not have students use technology or work together on activities as he had done in previous observations, he still maintained high cognitive demand within his activities. He worked to not only teach a challenging lesson, but also relate it to something with which students were more familiar, similar triangles. Even this was somewhat of a challenge. Sean reflected:

> The idea of visualizing the three right triangles was sort of the big new challenge from yesterday, to be able to rotate and reflect and so forth the triangles so that you can manipulate the picture to your advantage… Just getting them to say, "Hey, I can break out the triangles and set them up." There's some degree of perseverance in these problems, where in order to be consistently successful, you have to take the time to draw good pictures, apply the definition of similar triangles, and writing

proportions… The challenge then is to be able to get kids to follow through. (Sean, Interview 3, November 18, 2010)

While Sean recognized that he did not use *GSP* because he felt it lacked added opportunities, he also reflected that he did not have the student collaboration those activities normally provided in his class. When asked how he might alter the lesson, "I wish I had provided more opportunity for them to talk together about things… maybe partner or small group work and just listen to the way they're talking about it and given each other hints and help" (Sean, Interview 3, November 18, 2010).

Observation 4.

Technology Integration.

During Sean's final observation, students explored properties of rhombi and squares. For this lesson Sean was categorized as level 3 in Technology Integration. Sean was considered above level 2 as students used *GSP* with a partner to determine how to construct their own rhombus and square. They were also provided opportunities to explain and share their constructions during the whole class discussion. Sean was considered below level 4a as no activity included real-world problems.

To explore the rhombus, Sean did not provide any file or written instructions. Instead he wrote on the board, "A rhombus is a quadrilateral with 4 congruent sides" and gave verbal instructions.

Sean: What I am going to do is give you the definition of a rhombus and you are going to create it. The idea is that you are going to try and use the tools or commands we have to create it…The test will be if I can drag it and your construction is still a rhombus. How are you going to create something with four congruent sides? That is what you need to think about.

This task was the most unstructured activity that Sean provided for his students during any of the four observations. This activity required high cognitive demand as students were expected to create a construction from scratch and were given little instruction for completing the task. Sean reflected afterward that he enjoyed providing such a task, but recognized that it did limit time in class to explore additional properties of rhombi and squares.

> I like the technology. I like them just experimenting, though it's always like this trade off. I have to make this instructional decision. I definitely thought it was good that they could get to the end of the investigation with the rhombus and the squares… We didn't really have time to do the special properties today in class….So it's one of those things where if you had more time, you'd flesh it out frontwards, backwards… I was trying to do that a little bit with, I had a couple guys demonstrate things, hook up their computers and help me make things… I did the best I could with the technology. (Sean, Interview 4, December 9, 2010)

Instructional Practices.

During the final observation, Sean was characterized as level 3 for Instructional Practices. Sean was considered above level 2 because he used a variety of methods ranging from direct instruction to student-centered exploration. Additionally Sean provided multiple activities that varied in their cognitive demand. While the lesson focused on rhombi and squares, Sean pushed students to also connect relationships between the quadrilaterals in the family of parallelograms. Sean was categorized below level 4a as no activity incorporated real-world problems.

Sean began class by having students complete a warm-up to review properties of rectangles, which they had explored the previous day using *GSP*. The five problems were of low to moderate cognitive demand. For instance, one problem asked students to find the value of x when an expression with x was in one vertex of the rectangle. Another problem asked students to find the value of x in a rectangle that included the diagonals and required use of properties from previous units such as complimentary angles, angles formed by parallel lines cut by a transversal, and isosceles triangles. While students worked quietly on these problems, Sean checked homework and answered any questions about the warm-up problems. Afterward, Sean uncovered a transparency on the overhead projector with the solutions. Students asked about two of the problems, which Sean worked using a diagram on the whiteboard. Sean asked students low demand questions to help move between steps while he worked, such as the angle measure of the vertex of a rectangle or the relationship between alternate interior angles. While these questions were of low demand, Sean used them to reinforce the connections of how previously learned topics were needed to solve problems in quadrilaterals. Once the warm-up review was completed, Sean followed a similar pattern in reviewing the homework. He projected a new transparency with the homework solutions, answered questions, worked solutions, and called on students to help.

After completing all reviews of rectangles, Sean transitioned to having the students complete a high demand task using *GSP*. Sean asked students to construct a rhombus using only the knowledge that a rhombus has four congruent sides. Students began working very quickly on the activity and were engaged the entire time. Some students worked individually, others worked with a partner but on their own computers. While students worked, Sean moved around the room, talking with students, examining their constructions, and helping them identify if their construction held true at all times. Some students accidently made rectangles or parallelograms, which Sean then tried to give suggestions about what would need to be restricted to make it become a rhombus. Even with these incorrect constructions, Sean was happy and considered those constructions to be a success.

> Some of them today made a parallelogram in thirty seconds, which is a huge accomplishment because we took fifteen minutes yesterday and they couldn't make a parallelogram… The really good thing about that, even though it was the wrong shape, they were doing it quickly [and correctly]. (Sean, Interview 4, December 9, 2010)

Other students made restricted rhombi or squares. One student asked Sean to check her construction, which he exclaimed "Yes!" even though the partners had made a square instead of a rhombus. Later when discussing the construction of the square, Sean mentioned the two students by name. During the interview, Sean stated that he mentioned the students because they were typically reluctant to share during group discussions.

> I've got some people that are very reluctant to be in front of a group, be the person running the computer, things like that. They don't have a lot of mathematical confidence… I'm trying to have those people gain some confidence. In fact, the two girls who in the back corner typically would not be ones that volunteer actually did a pretty good job of making a rhombus. They made a square out of a circle today. And

so I made sure that everybody knew that we had some people that were doing it right and I tried to mention them by name and make them feel good about that. (Sean, Interview 4, December 9, 2010)

After about 20 minutes, Sean brought the class back together for class discussion. He asked one student to plug his computer into the projector, unhide the background objects, and share how he had created the rhombus. This student had two rhombi, although both were restricted in that neither could be dragged to create any general rhombus. Both rhombi had been created using two circles with the center of one circle serving as the radius point of the other circle (Figure 19). For the first rhombus, the student put points at the two intersections of the circles and connected the intersections with the circle centers. For the other rhombus, the student created a line through the two centers and a line through the intersection points of the circles. He then connected the four points where the lines intersected the circles to create his rhombus.

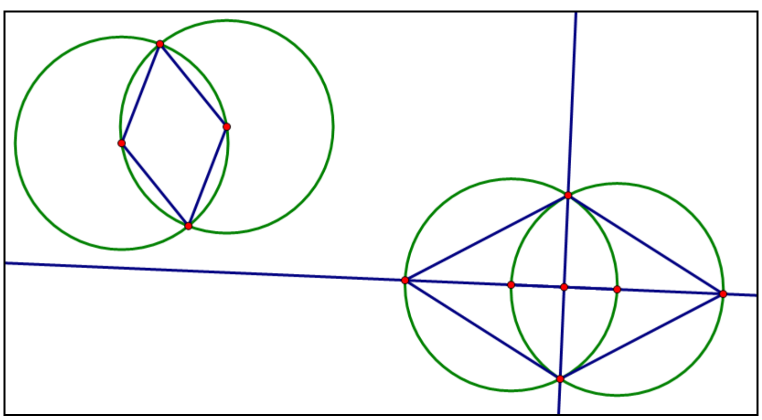


Figure 19: Example of two rhombi projected by a student

After the student shared how he created his rhombi, Sean thanked him. He then asked the student if he would be willing to create another rhombus while he explained to the class how to construct it. The student agreed. Sean then began explaining how to construct a fully dynamic rhombus with the help of the students.

Sean: Create a circle. Connect the center and the radius with a segment. Now create another segment from the center of the circle to the edge of the circle. We know something about these two segments.

Student 1: They're congruent.

Sean: Why?

Student 1: Because they go from the center the edge.

Sean: Right, they are both a radius of the circle. So we now have two sides. How can we get the other two?

Student 2: Draw a line through the two points on the circle. Then we can reflect across that line.

Sean: Good! So let's try that…

With this construction, Sean gave the students a starting point from which they were able to make a connection on how transformations could be used to construct the other half of the rhombus. As time was limited, Sean followed a similar pattern in helping students construct a square. He mentioned several students who had done so correctly. Again, he asked for student input to create a fully dynamic square.

With the final time of class, Sean gave students a worksheet that included additional properties of squares and rhombi, including when the diagonals were drawn. He suggested that some properties were known since both quadrilaterals were special types of parallelograms while others were more specific to each shape. Sean then read from the sheet each property that was unique to rhombi and the properties that were unique to squares. Sean explained what each meant by drawing a diagram on the whiteboard and marking it as necessary for his explanation. Next, Sean asked students to complete six problems that had students use the properties to find missing values in the given picture. Students worked quietly while Sean walked around the room answering any questions. As the problems used the same diagram, Sean drew it on the board prior to reviewing the problems. Afterward, he called on students to help him solve each problem. As they shared, he had them explain how they found their answer while he marked the diagram and wrote out the equations. Sean finished by giving students the last five minutes to begin their homework, which was continued practice on finding missing values in rhombi and squares.

Summary.

In the final observation, Sean provided students with an opportunity to explore the capabilities of *GSP* to create rhombi and squares. Sean suggested that the idea to let students create the quadrilaterals came from the professional development.

> We did do the thing with the different types of quadrilaterals as part of the professional development and the summer thing. So, just getting the technology in their hands and basically saying, "Give it a shot. Go for it. Try and make something." It's very instructive for me to watch them and see what they try. (Sean, Interview 4, December 9, 2010)

When asked what he might alter from the lesson, Sean again mentioned that his biggest weakness was not providing enough time for students to discuss what they were learning.

> We didn't spend a lot of time talking about ideas as much. Maybe making conjectures – we'd maybe like to see them making more conjectures about shapes and properties and things like that. So, that's one of the things that I think I would change. (Sean, Interview 4, December 9, 2010)

Even so, Sean provided students with opportunities to build their own personal understanding of squares and rhombi. Sean felt that allowing students to personally explore improved their engagement and provided deeper understanding than methods he had used before.

> I think they like [using technology]… You're investing time in something where you're saying, "Hey, if they can make it," and then at some point in the future, whether it's tonight's homework or EOC or things like that, if they're being asked to recall facts about the rhombus, they might be able to tie that to the time we spent doing that… I think you're investing in the properties and the construction and the time that you do, so that it's not just, "Hey, memorize this list of facts about this." So I thought that went well. I think that's important in what we do. (Sean, Interview 4, December 9, 2010)

Influence of the Professional Development.

Throughout the semester, Sean suggested that the professional development opportunities were influencing his lessons. For example, Sean mentioned that the triangle file in the second observation came directly from activities that were used during the first module in the online workshop. Additionally, he stated that from the Summer Institute, "I think the idea of linking a sketch to a Google Doc kind of came out of that. And that worked really well and it was relatively easy for me to do (Sean, Interview 2, October 7, 2010)." Also as mentioned during the fourth observation, Sean's idea for allowed students to construct quadrilaterals without guidance came from opportunities to complete similar activities during the professional development. Sean recognized the power in his own learning by having such opportunities during the Summer Institute that his students should experience the struggle and excitement of constructing for themselves.

One positive, unintended consequence from the Summer Institute was that Sean created a repository website that all of the Geometry teachers at his high school used to share files. As he stated,

> That's been kind of an idea that I got from the summer institute, was I really encouraged our math teachers, to – I said to them, "Don't we want, like, a repository for all of our sketchpad things? Then, if I like something of Rob's…my kids can access it very quickly." And that's why we have the [schoolonemath.com] website. And blam, it's been fantastic. (Sean, Interview 2, October 7, 2010).

The created repository led to more increased sharing of files and ideas on how to teach particular objectives better. For Sean, he even mentioned that it had continued to improve his attitude towards using *GSP* with standard Geometry students.

> I think in terms of my willingness to use it at all levels, it's changed. Now that I've got some things and we've got at least two other teachers here that are doing the same

things, I think that's really important for us to be able to share those things and debrief at the end of a lesson or at the end of semester. To just say, "Hey, if we tweak this sketch or that sketch, we might be able to combine these ideas or save us an extra day there and there." So those types of things are happening that I think the past haven't, you know, haven't happened. That's been a really good outcome. (Sean, Interview 4, December 9, 2010)

Characterization of Sean throughout the Semester.

In his four observations, Sean was characterized at level 3 for Technology Integration and Instructional Practices for almost every lesson as he worked to incorporate *GSP* into teaching Geometry for his standard Geometry students (Figure 20 and Figure 21). With Sean's experience in teaching and strong understanding of *GSP*, he was able to provide activities that allowed students to explore geometric concepts in ways he had not done before.

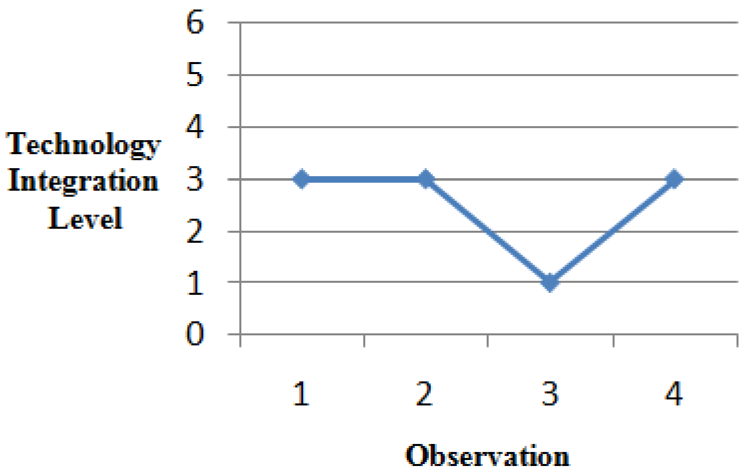


Figure 20: Sean's characterization of Technology Integration through the Four Observations

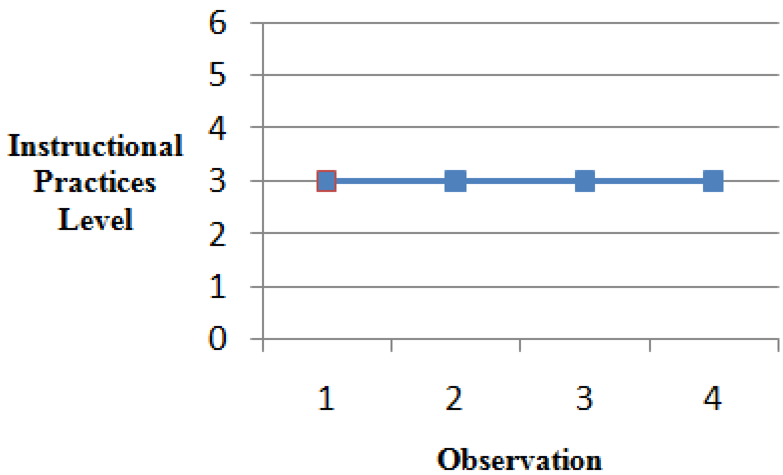


Figure 21: Sean's characterization of Instructional Practices through the Four Observations

Sean stated, "I've made a very concerted effort this semester to incorporate a lot more in that level class that I have this semester than I ever have" (Sean, Interview 4, December 9, 2011). Sean also recognized that the students in that class made him want to do more with *GSP*.

> I think one of the things that has kept me invested this semester, one is the students I have aren't discipline problems, they just aren't very fast at things… I'm willing to comprise some of the time aspects and time management issues that we have with the learning technology and the confidence level and skill building and things like that and making the conjectures. So, I've used a lot more time this semester to do that and I think I like that. (Sean, Interview 4, December 9, 2011)

To deal with issues of time while also maintaining high cognitive demand tasks that provided opportunities to explore and conjecture, Sean created a significant amount of pre-constructed files. Sean stated:

> In the past, a lot of times I've started with blank sketches and tried to build from there. This semester I've loaded premade sketches onto the website that they can download and then go from there. So that saved me some time. (Sean, Interview 4, December 9, 2011)

Sean felt his next step was to continue to make his activities more interactive and potentially add more project-based learning.

> I think the project thing has a lot of potential. I've got guys that I see them making some designs on their computer… I have one guy who's really into science fiction and he's taking the time to use line segments and circles and arcs and things like that and he likes to make these science fiction drawings and so he could get into projects that would be very based in some of his creativity and almost like artwork. So to be able to access some things like that would be kind of neat… I'm hoping in the future it sort of evolves into that for this level of class. (Sean, Interview 4, December 9, 2011)

CHAPTER 5

Themes Arising from the Cross-Case Analysis

Using the teachers' observations and interviews, several themes emerged from the cross-case analysis. These themes focused on the challenges and the supports in using *GSP* to teach Geometry. Challenges included: time; learning *GSP* and its limitations; scaffolding of activities; and handling student discourse. Supports included: success with GSP, ongoing professional development; and colleague support. While these challenges and supports created several obstacles for teachers, they also provided opportunities for growth in integrating technology into their instructional practices.

Challenge 1: Time

The challenge of time manifested itself in various ways throughout the semester. The teachers mentioned issues around the amount of time it took for students to learn a new software program, the amount of additional time needed for *GSP* activities, and the time needed to cover a broad Geometry curriculum. This challenge required the teachers to make choices in their activities and instructional practices that were reflected in their goals and outcomes of the lesson.

As the semester began, all four teachers stated that students struggled with remembering how to perform tasks in *GSP* such as measuring, constructing, and checking constructions using the drag feature. This often slowed *GSP* activities, which in turn required the teachers to rethink the time needed for upcoming lessons and activities. For example, in Sarah's first observation, students were given 30 minutes to complete a *GSP* quiz, but several did not finish by the end of class and had to complete it during lunch.

Afterward she reflected, “Some are just still, not struggling, but just are not comfortable and not quick with it. They can find it, if the time is there.” (Sarah, Interview 1, September 17, 2010). Reese reflected that part of this challenge was attributed to the students not getting their laptops as soon as school started. However, she also believed that the time needed to help students learn *GSP* may be minimized the second semester as students would have their laptops on the first day of class.

> Last semester, the kids didn’t have the computers yet, so I couldn’t start on the first day, saying, “Okay, let’s play with it.” This semester coming up, I will have two classes that will already have computers. So, being able to start day one and day two, say, “Here, we have this program. Let’s play with it a little bit.” I think that that will start to help. You know, the sooner they see it, the sooner they’re more comfortable with it. (Reese, Interview 4, January 4, 2011)

While the teachers mentioned having a few students who continued to struggle learning *GSP*, this challenge was minimized as the semester progressed. Most students appeared to gradually become comfortable using *GSP* to complete activities. By the end of the semester, students were observed using *GSP* to create, manipulate, measure, and calculate with minimal issues related to not understanding how to use the program.

In contrast, the challenge of time for activities and covering the curriculum continued to increase. With the challenge of time for *GSP* activities, the expectations of the lesson or activity influenced how they used *GSP* and whether it would be used differently if used again. In her second observation, Sarah had mixed feelings about the time she used for the *GSP* activity after her lesson on special right triangles.

> Usually, this lesson is difficult for them to remember. They get it that day and then, later on, they forget. So, I thought that, if they could actually see the connection themselves, then maybe they would retain it… [Yet] if I had to do it again, I might actually have them… let that be maybe a homework assignment because they really didn't need me to help them investigate. They could actually investigate it at home, and then we could have come in and discussed it because some were really quick filling out the table and others were slower, and so there was some downtime for some students. (Sarah, Interview 2, October 21, 2010)

Part of the tension for Sarah related back to the challenge of students needing time to learn *GSP*. Sarah mentioned later in the interview that some students were still very slow with using *GSP*, which in turn slowed down the activity. To her, if they completed it as homework, the students would still get to use *GSP* while her concern with timing would be minimized.

In comparison, Rob's thoughts on time for activities shifted as the semester progressed. During his second and third observations, Rob had concerns about the amount of time needed to finish activities. In Rob's third observation, he ran out of time while having students complete a *GSP* activity on relationships in similar triangles. This limited opportunities for student discourse within the lesson. He reflected, "I think having more of that discussion of what it means to be proportional and why these things are equal would be nice, but again time got the best of us today" (Rob, Interview 3, November 18, 2010). With the fourth, Rob expected his *GSP* activities to take longer, thus he built the time into his lesson because he felt it was important to provide opportunities for construction and discussion.

> Originally I had intended to get through triangles, and trapezoids, and the rhombus because that is what I had done in the past without Sketchpad. But that's a lot of just, "Here's the formula. Here's a worksheet. Memorize it. Let's move on…" I thought that realization was really powerful for them, and understanding how everything is intertwined… I didn't finish as much as I wanted to, but I knew I would be slower. So I wasn't really disappointed by that. I was surprised, like you said, how well they were working and how engaged they were in it. (Rob, Interview 4, December 9, 2010)

Sean made a similar statement after his fourth observation in which students were provided additional time to construct and share their rhombi and squares using *GSP*. He stated:

> I like the technology. I like them just experimenting, though it's always like this trade off. I have to make this instructional decision… You're investing time in something where you're saying, "Hey, if they can make it." Then at some point in the future whether it's tonight's homework or EOC or things like that, if they're being asked to recall facts about the rhombus, they might be able to tie that to the time we spent doing that. (Sean, December 9, 2010)

In addition to the time needed to complete individual activities, the challenge of time needed to cover a broad Geometry curriculum was also stated throughout the semester. For Sarah, some of her concerns with this challenge were alleviated by North Carolina removing the Geometry end-of-course exam.

> Because there's not a state exam, I have been able to implement [*GSP*], where, if I'd have had a state exam hanging over my head, I don't know if I would have done it as much. And it takes time, but when you first start implementing it, you're not, I guess, as familiar with it as you are the graphing calculators or any of the other forms of technology that I'm used to. So, it has given me the time to explore with it, with the students and myself. (Sarah, Interview 4, January 4, 2011)

Although the state exam was removed, the teachers still felt it was a challenge to cover everything within the curriculum. Sean suggested that this was part of the reason why he only used *GSP* to perform a demonstration during his third observation.

> We have had times where we've constructed some other sketches. I just didn't want to do it yesterday. I feel like that section can sometimes run across two days and I wasn't willing to do that with that particular one… We have a bunch that we have left to do this semester. So from a teaching perspective, I was not willing to take more than one period on this topic. (Sean, Interview 3, November 18, 2010)

Trying to complete the curriculum was especially apparent during the final observations of Sarah and Reese. Due to inclement weather, both were observed in January during the final week of the semester instead of in December. The challenge of trying to get every topic covered by the end of the semester forced both teachers to use a combination of lecture, demonstration, and practice problems. Sarah reflected, "I thought the biggest obstacle really was the time constraint, that we had to get, you know, all this done in this compressed amount of time" (Sarah, Interview 4, January 4, 2011). Reese agreed, stating, "This is the last lesson that we had to do for the semester and so, in trying to be as compact as possible, I gave them the notes and just worked examples" (Reese, Interview 4, January 4, 2011).

Challenge 2: Learning GSP and its limitations

While dealing with multiple challenges of time for using *GSP* in lessons and activities, teachers also had to learn the capabilities and restrictions of *GSP*. With his second observation, Rob found the newly learned "Snap Points" capability useful, but he did not initially recognize that distance measurements in *GSP* were limited to positive measures. This became a problem when he asked students to find the slope of the line by dividing the "Rise" measurement by the "Run" measurement. He reflected on this afterward:

> One of the things we had trouble with and we changed on this one as opposed to what we had before was having the rise and the run snapped to the integers on the grid so that when they saw the rise over the run, it wasn't crazy decimals. It was something much more easy for them to understand the division that was involved. So we came up with a way to snap them to the points, but then I didn't even think about it until I came in about how there wouldn't be any negative slope because the lengths were always positive. (Rob, Interview 2, October 7, 2010)

Sarah ran into a limitation as well during her third observation. The method students used to construct the central angle, inscribed angle, and corresponding arc, the inscribed angle could be dragged to actually open the opposite direction of the central angle. One student even mentioned this problem during the class discussion. Sarah reflected:

> I didn't know how to keep it from going past the original vertex so that it was always true. Because when she crisscrossed the measures, you know. But I don't think that

was a big problem because once I said, “Don’t cross over that vertex, they stopped doing that and then they could see the relationship.” (Sarah, Interview 3, November 12, 2010)

In addition to such issues that arose during observations, the teachers also mentioned specific topics that they struggled in finding ways to use *GSP*. Early in the semester, the unit on logic caused both Sean and Rob to think about if and how *GSP* could possibly be involved. Sean stated, “Up until this time, I mean, you talk about things like ‘What’s the converse of this if-then statement?’ I mean that’s a little harder to do on Sketchpad” (Sean, Interview 2, October 7, 2010). However, Sean found a way during the first observation to integrate in a *GSP* activity that allowed students to collaborate and conjecture while meeting his objectives for that specific lesson in the logic unit. In contrast, Rob tried creating a *GSP* activity for the laws of detachment and syllogism in the logic unit, but did not feel it met his goals for the lesson.

> I spent some time thinking about how I can have them look at something on Sketchpad and deduce and things like that… I did put some stuff together... What I decided was we would have so many different if-then statements or so many different conjectures from that that we wouldn’t be able to come together as a class and have a discussion about it because they all would have seen different things. Or, I didn’t want them to have to make a conjecture to be the reason they weren’t able to get through the deduction part of the lesson. (Rob, Interview 1, September 20, 2010)

Both Sarah and Reese mentioned their struggles in creating *GSP* activities with the final lessons of the semester as the topics became more complex. Both mentioned surface area and volume as two such topics for which they could not figure out how to use *GSP*. Reese reflected:

> We have the Sketchpad stuff, but I don't know how to do the volume in there. I don't know what its capabilities are, so I just went with something that was fairly easy to use to put problems up on the board and just have them plug in their calculators and give me answers that way. (Reese, Interview 4, January 4, 2011)

Even with issues learning *GSP* and its restrictions, all four mentioned they used *GSP* whenever possible. Rob stated, "I've used it in almost every chapter to investigate something" (Rob, Interview 4, December 9, 2010). Reese's final reflection best summarized how most dealt with the challenge of learning *GSP* and its limitations.

> I think that, as the semester progressed, we used it more and more until I got to the point where I don't know how to do, you know, certain things in it. And we kind of stopped using it. They still use it for their notes from time to time, putting pictures in when we were doing surface area, but… so everything that I think that we've learned, everything that I could find something for, I think that we used Sketchpad for it. (Reese, Interview 4, January 4, 2011)

Challenge 3: Scaffolding of Activities

As the teachers worked to learn the capabilities and restrictions of *GSP*, they were also learning how to create lessons and activities that incorporated *GSP*. This included decisions on whether students would use preconstructed activities or have to construct the objects, what should be teacher-guided versus student-explored, and methods of questioning.

Throughout the semester, teachers continued to deal with the challenge of what students should be constructing and what should be provided in their *GSP* activities. Sean stated that he decided to create many premade files this semester to save time in class.

> I've also found that in the past, a lot of times I've started with blank sketches and tried to build from there, and this semester I've loaded premade sketches onto the website that they can download and then go from there. So that saved me some time. (Sean, Interview 4, December 9, 2010)

Rob reflected that during the first half of the semester, he felt he needed to use more premade sketches to build the students' understanding of how *GSP* worked.

> There's too many little hidden things to make the sketch work that I would have them make this. But it's enough using the calculator and the measurements that it's enough to go "Oh, I didn't know I could do this," and start doing this on a regular basis, and building up that foundation takes time. (Rob, Interview 2, October 7, 2010)

Having students construct also added a challenge of maintaining mathematical fidelity. Teachers could check their premade files for any limitations or issues students may have in completing activities. However, when students constructed, the teachers had to monitor and verify that students were correctly doing so. While construction-based activities engaged students during Rob and Sean's final observations, Reese and Sarah both had lessons where student constructions caused problems. For example, students struggled creating the right triangle in Reese's second observation, thus many never even began the activity of exploring the similar triangles within the construction. In Sarah's third observation, several students incorrectly constructed the necessary circles for each task. This caused Sarah to quickly demonstrate a method for correctly constructing each object so that students could explore the relationships in each circle. Both Sarah and Reese recognized afterward that the struggles were caused by not providing clear guidance or instructions. Reese suggested:

> I had hoped that setting the students up, by asking how to create a right triangle would send them on the right track; however, many of them just worked with the measures until they had 90 degrees and did not construct a right triangle. This idea would not make the triangle proportions work correctly I tried to lead the students through the construction. After that about half of the students completed the project correctly while others forgot they were trying to measure angles and not just make a triangle... In the future I would set up the triangle with the students first, then have them measure the angles and complete the activity. (Reese, Interview 2, October 21, 2010)

However, Reese used this experience to refine her approach for students constructing their own objects. In her third observation, Reese provided students with a worksheet that guided them through the constructions and relationships for which they were to explore. This appeared to be more successful as students were engaged during the entire activity and appeared to complete the tasks.

> I've found that if I have a structured kind of worksheet or questions for them to work through, that they are very good about, "Okay, I'm looking at this. I need to do this process next. I need to… okay, she wants me to find this. How do I find this? Okay, here's how I do it." And they are very good about walking themselves through

> projects, as long as I have it outlined step-by-step, which is why I did the nice little worksheet for them. (Reese, Interview 3, November 12, 2010)

Once the teachers determined whether to utilize premade constructions or have students start with a blank file, they had to balance teacher guidance with student exploration within the activities. With his second and third observation, Rob mentioned that he provided more guidance because he was not sure students had the understanding of *GSP* to complete the tasks on their own.

> You know you really still have to encourage them to kind of drag it and test all the different situations and to think about why that's the way it is. I put specific questions in there in response to make conjectures to kind of lead them to do that. (Rob, Interview 2, October 7, 2010)

However, after the third observation, Rob reflected that his guidance may have limited his ability to determine what students understood and what they still needed to learn.

> I really wonder if they know what it means to have equal ratios. I kind of, we kind of led them towards the proportions we want them to write, but do they understand what it means to be proportional and how does equal ratios allow us to say that? (Rob, Interview 3, November 18, 2010)

By the final observation, Rob used his experiences to change his instructional practices. Instead of guiding first and then allowing students to explore, Rob allowed students to first explore, conjecture, and share ideas before discussing the topics. During whole class discussion, Rob allowed students to build off each other's ideas and would do so by asking students to justify or explain their conjectures.

In comparison, Sean worked to balance guidance and exploration throughout each observed lesson. During the first observation Sean led whole class discussion on determining a conjecture for the first four pages of a *GSP* file on deductive reasoning. The next four pages were completed through student exploration either individually or with a partner. To Sean, this scaffolding was meant not only to build conceptual understanding of deductive reasoning, but more importantly it was intended to build student confidence.

> I think the reluctance to give an answer and to stick your neck out a little bit and try and support your own answer is because of the confidence issue. So, to give them – you know, I tried to give them some things on the computer where they could do some investigating, learn some things, measure some things, get some information. Trying to back up their own thinking about, "Yeah, I think this is going to be true or false." You know, that all plays into that confidence issue. So, I think that's got to be the biggest thing, you know, as part of this lesson or working with this class. (Sean, Interview 1, September 20, 2010)

Sean typically combined guidance and exploration so that students could be successful. His goal was to just get "the technology in their hands basically saying, 'Give it a shot. Go for it. Try and make something.' It's very instructive for me to watch them and see what they try" (Sean, Interview 4, December 9, 2010).

Finally, the teachers were consistently thinking about their questioning and how this influenced students' understanding. Early in the semester, Sarah, Reese, Rob often asked low demand questions that required short responses with no justification or explanation. This changed throughout the semester, especially when *GSP* activities were used. Rob recognized that as the semester progressed, his questioning skills improved.

> I think with time, I've become more comfortable with saying the right things to get them to the think the right thoughts. You know, that's something that is always going to be an issue, and I thought that investigation was going to be a lot more of me, "Well ok, don't click this. Highlight everything. Transform. Rotate." But they understood that process well enough to where they really got to be able to, "Ok, that didn't work. What else can we try?" or "Is it the wrong point or the wrong angle?" (Rob, Interview 4, December 9, 2010)

Of the four, Sean was the only teacher who emphasized justification and explanation of solutions throughout the entire semester. From the first to the fourth observation, Sean stated he was trying to push students beyond their comfort zone and have them explain their reasoning for their solutions and conjectures.

> They're more willing to just say, "Oh, that's true," or "Oh, it's false." But then they stop there, so what we're trying to get them to do here, early in this chapter is just finish that thought. Why are you saying it's false? Why did you think it's true? Could you prove to me that it's true? (Sean, Interview 1, September 20, 2010)

Challenge 4: Classroom Discourse

A final challenge that the teachers continued to address throughout the semester was student discourse. Determining how to incorporate classroom discourse was especially important as it is a primary component of learner-centered practices. Through observations and interviews, two major challenges of discourse arose: how to manage students to maintain on-task discussion; and how to enhance student discourse.

Managing the discussion that occurred in classes was addressed or observed with Reese, Sarah, and Rob. While not observed, Sarah commented about the students talking in almost every observation. After the third observation, Sarah stated, “They’re a social class, so I try to do discovery with them, but then sometimes I have to pull back because they get off task very easily” (Sarah, Interview 3, November 12, 2010). However, Sarah also recognized that many students were participating in on-task discussions that were focused on learning. During the third observation she also reflected, “I saw them sharing their pictures and looking and talking. So I felt like they were already talking about it, a lot of them” (Sarah, Interview 3, November 12, 2010).

While Sarah was concerned that off-task discussion might occur, Reese struggled to maintain on-task discourse throughout the semester. During her four observations, there were times when students did not complete *GSP* or paper-based activities and instead sat talking off-task. This was especially an issue during the second observation with the right triangle *GSP* activity. Reese attributed this to students placing her as the authority of the class and not feeling confident in trusting each other’s conjectures and deductions. After the second observation, she stated, “The students still want to ask me more questions than their classmates” (Reese, Interview 2, October 21, 2010). Even after the third observation where students were engaged in the transformations activity, Reese reflected that she still struggled with getting students to discuss.

> As long as it's an activity that is fairly straightforward, I don't think there's too much of a challenge in getting this crew to talk about it. If it becomes a little bit more involved, the more frustrated they get with it… the less likely they tend to talk about stuff. They tend to then go, you know, "Me, me! Help me! Help me!" instead of helping each other more. (Reese, Interview 3, November 12, 2010)

One way that Sean and Rob found discourse to be effective was to utilize partners during *GSP* activities. Early in the semester, Rob was against using partners as he felt that instead of enhancing discourse and collaboration, "one person kind of sits there and does it all" (Rob, Interview 2, Octoboer 7, 2010). However, by the final observation, Rob stated, "When I use Sketchpad, I definitely almost always use pairs or small groups" (Rob, Interview 4, December 9, 2010). He suggested that this helped both with *GSP* technical issues and it provided each student with someone to discuss what was occurring in the activity. Sean found partners to be beneficial in building student confidence and learning Geometry.

> They're adding value when they're together. It is. I mean, I saw that today, so that was one of the most obvious things that came about. I mean, I'd even make a list of nine different interactions that I had with at least one or two students that were maybe working together on something that I thought were very valuable and I, I can individually remember those things and so I know that there was value that was there. (Sean, Interview 2, October 7, 2010)

Support 1: Success with GSP

While the multiple challenges were prevalent throughout each teacher's observations, the success teachers felt when they used *GSP* activities served to support the continued use of *GSP* throughout the semester. For example, the teachers consistently spoke positively about *GSP*, what it was doing for their students, and how much more students appeared engaged in the activities. The improved engagement was also observed by the researcher as students were often more on task during *GSP* activities than during any other part of the lessons. Rob stated, "I think something about Sketchpad kind of gets them to work on things a little bit more" (Rob, Interview 3, November 18, 2010).

The teachers suggested that the perceived engagement was created by several of *GSP*'s capabilities. Both Reese and Sarah discussed how *GSP* supported their visual learners in being able to see what happens to properties/relationships when objects are manipulated. Sarah suggested:

> I think that [*GSP*] has really helped my visual learner. Where before I would try to do things visually by using models and things, but this allows them really to play and fool around with it and really be able to look at it in different ways. (Sarah, Interview 4, January 4, 2011)

Reese shared, "I think that they did well using the Sketchpad to actually explore it and then be able to kind of see the relationship and then discuss that relationship" (Reese, Interview 3, November 12, 2010)

The teachers also believed that the use the drag feature provided opportunities that could not be done easily with paper and pencil tasks. Rob stated:

> Sketchpad lets you look at so many cases all at once… that is what I wanted it to do, is to see a lot of examples, and for them to be able to test a lot of cases quickly but effectively. (Rob, Interview 2, October 7, 2010)

Reese suggested the ease for creating multiple representations by dragging also improved student engagement in her classes.

> If they just had a pencil and paper, I'm not going to get about half of them to actually… to actually play with it and to work with it as you do with the technology because it is fairly accessible to them. They're able to get in there and manipulate it, whereas, with pencil and paper, they might not be as willing to do that. (Reese, Interview 1, September 27, 2010)

In combination with dragging, all four teachers used features of constructing, measuring, and calculating throughout their *GSP* activities. In Sarah's second observation, while completing the special right triangles activity, one student exclaimed out loud that she was noticing a pattern after measuring and dragging different vertices. Similar excitement was observed both in Sean's second and fourth observation when students were constructing their own objects in *GSP*. In Sean's fourth observation, one group of girls was observed working at making a rhombus. They created, measured, dragged, and revised until they created a dynamic square that maintained all properties when manipulated. While the initial activity was to construct a rhombus, in their excitement, they called Sean over and shared their success in creating a square.

In his third observation, Rob said that he specifically used *GSP* because he wanted students to have uniform calculations while examining ratios in similar triangles. He stated:

> [*GSP*] basically let them see that the ratios were the same without the error of measuring with the ruler. That sounds silly, but having someone measure something of 5.7 and somebody else measure 5.6 and 5.9, it leads to too much confusion with looking off of neighbors and things like that to reach a common understanding of things being equal. Sketchpad, since it all measured out the same, took away that confusion in measuring. (Rob, Interview 3, November 18, 2010)

Finally, the four teachers all suggested that the value of *GSP* came from more than just the ability to construct, measure, calculate, drag, etc. The teachers believed that *GSP* provided students opportunities to discover geometrical relationships as well as build their reasoning skills and conceptual understanding when used with an appropriate task. Sarah summarized this by reflecting:

> I've been trying to use a lot of Sketchpad, hoping that, with them creating, creating their own angles or creating their own triangles that, when they create them and they measure them and I ask them, "You come up with your own theorem" that they're going to take more ownership in it and it's going to be something that they basically can remember. In six weeks, they're going to remember that. Or, if they don't remember that, they understand how to recreate it and figure it out. So, I'm hoping that, in the long run, that they are going to become that independent learner (Sarah, Interview 3, November 12, 2010).

Support 2: Ongoing Professional Development

While the teachers dealt with various challenges in teaching Geometry with *GSP*, the professional development opportunities provided multiple supports for them throughout the course of the semester. This included helping teachers build their skill set with *GSP*, providing teachers with activities that they could use within their classes, and providing continuous learning that modeled student-centered practices.

Throughout the semester, the most noted aspect of the professional development was the increased skill set it provided around using *GSP* to build activities. Sarah stated that almost all her knowledge of *GSP* was due to the professional development. Rob mentioned that he continued to add to his skill set with each module of the professional development as well, from using features such as "Snap Points" to constructing complex objects. Reese reflected that the professional development enhanced her skills as well. "I knew how to do some pretty simplistic stuff, but I know how to do a lot more now and a lot more connected-type stuff instead of just simple basics" (Reese, Interview 4, January 4, 2011).

The teachers also mentioned they were using activities from the professional development within their classes. For example, Reese used multiple professional development activities throughout the semester such as a project to determine the optimal location for an amusement park between three cities, an activity for constructing an animated Ferris wheel, and several others. Sean incorporated the animated Ferris wheel as a project as well. He also included a triangle construction activity from the online professional development with his *GSP* activity during the second observation.

One unique idea that was gleaned from the professional development was Sean's concept of building a school repository for *GSP* files. *Scaling Up* provided a website in which participants were to create and post *GSP* activities and lessons. Sean thought this was a great idea and decided to make a similar site for the math teachers at his school.

> And that's been kind of an idea that I got from the Summer Institute. I really encouraged our math teachers to, I said to them, "Don't we want like, a repository for all of our Sketchpad things. Then if I like something, Rob an access it and, so kids can access it very quickly. And that's why we have the [schoolBmath.com] website. And blam, it's been fantastic. It's just so simple for me to post things there. And then even the other teachers can open up things and go, "Oh, I could use some of that in class, I don't know about all of it, though." And then they can modify and post their own things. (Sean, Interview 2, October 7, 2010)

Finally, the professional development provided continuous learning throughout the semester. Sarah reflected, "Going to the Summer Institute and doing the staff development online, it has kind of kept me going with [using *GSP*]. I think that if I had just stopped, I would have forgot things" (Sarah, Interview 4, January 4, 2011). Rob stated that the continued professional development's methods had given him the confidence to refine his own teaching and to incorporate more student-centered practices.

> I feel much more confident in my ability to bring in things like Sketchpad. And I think it's helpful. I think it allows me to do a lot of investigating that I haven't been able to do in the past. (Rob, Interview 4, December 9, 2010)

Support 3: Colleague Support

A final support that helped two of the teachers deal with the challenges of teaching in a technology enhanced learning environment was the support of their colleagues. At Rob and Sean's school, the teachers often shared, refined, and collaborated on their lessons. Both stated how this had given them ideas throughout the semester for creating, sharing, and improving *GSP* activities. In the first lesson, Sean reflected that his colleagues helped him improve the *GSP* deductive reasoning activity.

> I came up with it. I sent it to [the other teachers], and they gave me some comments on it… One of the things that I did on the sketch was – a couple of sketches in – you know, Rob had given me this suggestion, about what if you said, rather than just make a conjecture, what if you actually said, "Such and such student makes the conjecture about this picture, blah, blah, blah" and have the students evaluate somebody else's conjecture. I think that's a really valuable thing for them to disprove somebody else. (Sean, Interview 1, 2010)

Rob suggested that the other teachers were continually sharing files and helping him improve his files as well. For example, in the second observation, Rob stated, "I took what Sean and [another teacher] had put together a little bit and changed a little bit" (Rob, Interview 2, October 7, 2010). With the third lesson, Rob reflected that Sean gave him the file he used, but then he refined it based on how he wanted to teach the lesson.

> Sean came by and said, "Hey I made this." And it was exactly what I was looking for, exactly what I needed… Sean talked to me about how he had went through it pretty quickly just to kind of show they were the same and did sample problems all at the end. What I kind of decided to do was to have that kind of guided notes, and talk about the perimeter and do a couple, then talk about the median and do a couple. (Rob, Interview 3, November 18, 2010)

Both suggested that the collaboration with each other and several other teachers at their school had been a significant help in their creation of *GSP* files and activities. Rob stated, “When tricky things do come up, between me, Sean, [and two other teachers], we’re always able to knock it out or trick it into doing what we want somehow or someway” (Rob, Interview 4, December 9, 2010). Sean agreed with this and suggested the professional development opportunities had made this possible.

> We’ve got at least two other teachers here that are doing the same things. I think that’s really important for us to be able to share those things and debrief at the end of a lesson or at the end of semester. To just say, “Hey, if we tweak this sketch or that sketch, we might be able to combine these ideas or save us an extra day there and there.” So those types of things are happening that I think the past haven’t, you know, haven’t happened. That’s been a really good outcome [of the professional development]. (Sean, Interview 4, December 9, 2010)

Cross-Case Analysis Summary

While the four teachers of this study each had unique experiences in teaching Geometry, their interviews and observations suggested they experiencing similar challenges and supports that influenced their instructional practices and how they integrated technology into their lessons and activities. The teachers were dealing with challenges of time, learning a new tool, learning how to scaffold activities using *GSP*, and how to support appropriate classroom discourse. However, they were also supported by continued success in their activities with *GSP* in that students often were observed to be more engaged in the tasks. Additionally, ongoing professional development provided opportunities for the teachers to develop new skills, new activities, and new ideas on how to integrate *GSP* into teaching and learning. Finally, support of other teachers provided two teachers an opportunity to collaborate throughout the semester on creating, sharing, and revising *GSP* activities that each made. Sarah summarized that the entire experience "has been an aid as far as getting that type of instruction into my classroom" (Sarah, Interview 4, January 4, 2011)

CHAPTER 6

Discussion

The purpose of this study was to explore teachers' instructional practices and integration of technology while participating in face-to-face and online professional development. During the first semester following the face-to-face Summer Institute, changes were observed in teachers' integration of technology and instructional practices. The teachers stated they were using technology more often in their lessons and activities than in prior years. Additionally, the teachers were observed integrating more learner-centered practices, especially when utilizing *GSP* activities.

The transitions in instructional practices were influenced by the challenges and supports that existed in teaching Geometry in a technology-enhanced learning environment. While the teachers suggested that they used *GSP* more often in lessons, they still dealt with the challenge of time both in completing daily activities and in planning an entire curriculum, the challenge of learning a new software program and its restrictions in teaching Geometry, the challenge of determining how to appropriately scaffold *GSP* activities, and the challenge of allowing and managing more student discourse within the classroom. However, teachers found support in the continued success of utilizing *GSP* in class, the confidence, skills, and activities they were obtaining from ongoing professional development, and opportunities to work with colleagues to collaborate, create, share, and refine new *GSP* activities.

The themes that emerged from this study resonate with findings from other research. For example, the challenge of time is a consistent challenge for teachers trying to integrate technology into their lessons. Kor and Lim (2009) found that although participating teachers gained confidence in teaching with *GSP* and had student increases in engagement, work quality, and achievement, teachers continued to have concerns around the amount of time needed to create and implement *GSP* lessons. Several teachers even mentioned that if they had not been part of the lesson study, they would not have likely continued creating *GSP* activities, due to time constraints. Similarly, Hannafin et al. (2001) found that while students showed increased engagement and success with the end-of-unit test after completing a unit that used only *GSP* activities, the teacher was still concerned about not having enough time to cover the curriculum before the state exam. In a survey of 92 teachers, Pierce and Ball (2009) found that while a majority of the teachers believed that using technology motivated students, made learning more enjoyable, provided opportunities for in-depth learning and real-world problems, there were also significant concerns with time needed for technology-enhanced activities and covering the breadth of required curriculum. Interestingly, Pierce and Ball found significant interactions within their survey around concerns of time. For example, teachers who believed students should learn mathematics by hand also believed technology took too much class time. A second interaction suggested that teachers who did not believe there was enough time to cover the curriculum with technology were also concerned about the loss of personal time to learn new technologies.

Previous research also supports the challenge that time is needed for teachers to learn the capabilities and restrictions of new technology. In surveying teachers about their use of computers in the mathematics classroom, Manoucherhi (1999) found that lack of opportunities for teachers to participate in professional development and to learn about the new technologies they were expected to implement often led to failed implementation in the classroom. Manoucherhi suggested lack of success occurred as teachers were then expected to find time outside of school hours to not only learn new technologies, but also learn how to use them to teach. “The consequence of this practice is obvious… the use of technology becomes yet another addition to an already crowded daily schedule” (p. 38). Darling-Hammond et al. (2009) suggested that limited opportunities for professional development have become the norm as well. “More than 9 out of 10 U.S. teachers have participated in professional learning consisting primarily of short-term conferences or workshops” (p. 5), most of which were less than 16 hours over two days. .

The challenge of determining the appropriate scaffolding for *GSP* activities has been identified as a concern expressed by teachers in other studies as well. MacGregor and Randall (2002) examined how scaffolding would influence student attitudes and achievement while using *GSP* in completing a unit on transformations. Results suggested that the students who were provided guidelines and support in completing problem-based activities performed significantly higher on the end-of-unit exam than students who were provided the activities with no guidelines or support. Journal entries by the students suggested that the supported students felt less frustration in completing the *GSP* activities. In comparison, Hannafin (2004) found that the scaffolding needed might also depend on the group with which one is teaching. For his study, Hannafin created a *GSP*-based with 14 activities. Two classes were provided no structure, and were told to complete the activities while two classes were provided a guided introduction to *GSP* and additional guidance throughout the unit. On the post-test following the unit, low-ability students performed better in the less structured group while moderate and high-ability students performed better in the structured program.

As teachers begin implementing learner-centered technology-enhanced lessons and activities, incorporating student discourse becomes an additional challenge. However, this challenge has been observed in non-technology-based as well as technology-enhanced classes. Stein et al. (2007) stated, "At the heart of the challenge… is the need to strike an appropriate balance between giving students authority over their mathematical work and ensuring that this work is held accountable to the discipline" (p. 332). In performing a case study of four teachers using *GSP* to teach a unit on measurement, McDougall (1996) found that the teachers who struggled the most with discourse also saw the role of teacher as a figure of authority that must control the class at all times. McDougall concluded, "Students need to communicate with each other. This communication could cause anxiety for teachers who feel that classrooms should be quiet, or that only one person should be talking at a time" (para. 48).

The supports identified in this study have also been corroborated with previous research. For example, as teachers see increased student engagement, motivation, and an improved quality of work, they want to continue using *GSP* to teach. In Kor and Lim's (2009) study, teachers who participated in a year-long lesson study not only gained confidence in teaching with *GSP*, but they also observed improved motivation and quality of work from their students such that almost every teacher was interested in continuing the lesson study groups the following year. Shafer (2008) suggested that as the participating teacher in his teacher development experiment observed increased engagement and improved student work during weekly *GSP*-based lessons led by the mentor, the participating teacher became more confident in using *GSP* in his class and shifted towards using more learner-centered practices. Keeler (1996) suggested that after providing professional development on utilizing this technology for 13 teachers with technology-enhanced elementary classrooms, the teachers were observed the following year using more learner-centered practices. In addition, students were observed being more on-task, engaged, self-motivated, and were more willing to participate in classroom discourse.

While student success with *GSP* encouraged teachers to continue incorporating such activities into their classes, professional development opportunities often initiated these changes and provided opportunities to collaborate with colleagues. Within this study, the teachers suggested that the ongoing professional development improved their skills, their confidence, and their instructional practices, which was supported through classroom observations. Kor and Lim's (2009) success with teachers originated with a year-long lesson study program in which groups of four teachers would regularly meet to practice and collaboratively plan lessons with *GSP*, observe each other teach, reflect afterward, and use the reflections to revise and re-teach. Teachers improved their skills in using *GSP*, creating *GSP* activities, and they used more learner-centered practices. Similarly, Stols, Mji, and Wessels (2008) provided workshops in using *GSP* and using *GSP* to teach the geometry topics in 11^{th} and 12^{th} grade mathematics. Upon completion, all teachers stated that the workshop had made them more confident not only in using *GSP*, but also in teaching Geometry. A pre-test/post-test showed a significant improvement in the teachers' knowledge of geometric topics, especially in solving high demand problems.

Limitations

This study involved a limited number of participants, each with only a few observations. The observations were also set up to accommodate the participants schedules, thus it was possible that teachers could have specifically incorporate *GSP* on days in which they knew they were being observed. However, this was not a major concern. One reason was that at least one observation from each teacher included limited to no use of technology. While it is not known how often *GSP* was actually used in each class, students' increased ability in using *GSP* suggested that teachers were regularly incorporating *GSP* activities. Throughout the semester, students were observed not only becoming more adept at using *GSP*, they were also observed using it to perform constructions that likely could not be completed without regular use of the software in the class.

Future research could address the concern of limited observations by having teachers complete weekly journals that list the day's topic, the activities planned, and how different technologies like *GSP* are being utilized to support those activities. Another option would be to utilize the Scoop Notebook method (Borko et al., 2007). With this method, various classroom artifacts are collected over the course of a week that could help provide information about typical instructional practices. These artifacts can include lesson plans, handouts, scoring rubrics, student work (low, medium, and high quality) from each activity, pictures of the classroom (overall layout, writing on boards, writing on overhead, etc.), and assessments. These notebooks could correspond to the week in which the teacher is observed to provide a better overview of what students learned prior to the observation and what they would learn in upcoming lessons.

An additional limitation was the limited differentiation of lower levels within the LoTi. While the LoTi provides a broad scope of technology integration and instructional practices with an emphasis on student-centered real-world applications, it does not provide detailed distinctions within the lower levels of the framework. For example, no teacher was ever considered below level 2 because no teacher lectured the entire 90 minute class. However, what occurred at level 2 among the various observations was often very different. For example, Rob's instructional practices were considered level 2 for his first three observations. However, his first observation was very different from the following two. The first observation had students sit quietly, copy notes, and work review problems, the second and third observation had students using *GSP* to answer questions individually and those posed by Rob. However, due to the low cognitive demand of the questions and limited collaboration, the lessons were considered level 2 for as well. To handle such issues, the lower levels could be expanded upon and further examined to determine the appropriate number of levels. One possibility would be to split level 2 into at least two levels. The first level would follow the tenets of direct instruction. The second level could include student opportunities to collaborate, however the activities would be of low cognitive demand.

Implications

This study observed how four teachers' instructional practices and technology integration changed while participating in on-going professional development. The results of this study provide consideration for both future professional development and future research. First, this study supports continuous research that on-going content-specific long-term professional development can provide change, in this case, in teachers' instructional practices and integration of technology (Darling-Hammond et al., 2009; Garet et al., 2001; Yoon et al., 2007). At the same time, this study suggests that there are multiple challenges that teachers face that can inhibit their full implementation of technology-enhanced learner-centered lessons. It may be necessary for professional development educators to continually investigate how these challenges can be mitigated or discussed during the professional development events. Within the professional development that the teachers were participating in during this study, such challenges were not explicitly addressed during the face-to-face or online workshops. By exploring these challenges as a group during trainings, teachers may become better prepared to handle them while they are in the midst of teaching.

Additionally, this study suggests that observing participants can provide not only additional opportunities to coach and mentor newly-implementing teachers, but it also can provide a better opportunity to understand the challenges that the participants face in a regular school day. This may be especially necessary for educators leading long-term professional development so that they can continue to enhance and customize the learning opportunities to better meet the needs of the participating teachers.

This study also suggests that professional development educators should promote teacher collaboration not only during workshops, but also when teachers go back to their schools. Having multiple teachers participating in the same workshops and teaching the same subjects provided one of the observed schools with multiple teachers that could collaborate, share, refine, and create new *GSP* activities. This appeared to have a positive influence on both Rob, a relatively new teacher, and Sean, an experienced teacher. More research should be conducted to explore how such learning communities can influence instructional practices and technology integration as well as how teachers at small schools may be able to form online communities to support such learning.

Finally, this study indirectly implied that *GSP* could have a positive influence on student engagement and work ethic. Although this study did not explore student perspectives, activities that integrated *GSP* typically provided more opportunities for student discourse. In turn, students were more actively engaged during these tasks than during other tasks in observed lessons. Engagement in discourse can provide teachers an opportunity to learn what students understand and what may still need to be addressed in future lessons.

Conclusion

Professional development can provide unique opportunities for teachers to experience, explore, collaborate, challenge, and create new innovations for their students. In this study, the 1:1 classroom setting provided a unique opportunity for teachers to allow students individual access to a software program that can make learning Geometry become dynamic and engaging. While teachers in this study are still transitioning in their use of more learner-centered practices, they were able to make considerable changes in less than a semester. As Rob stated:

> I think the Institute has shown me that it is a lot easier than what I might think it may be… I feel much more confident in my abilities to come up with worthwhile sketches to use in the classroom [, and]… I think it [has allowed] me to do a lot of investigating that I haven't been able to do in the past. (Rob, Interview 4, December 9, 2010)

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APPENDICES

Appendix A

***Scaling Up* summer institute topics with Common Core Standards**

Topic	National Common Core Standards
Representing and defining Constructing versus drawing	**CO: Experiment with transformations in the plane** 1. Know precise definitions of angle, circle, perpendicular line, parallel line, and line segment, based on the undefined notions of point, line, distance along a line, and distance around a circular arc. **CO: Make geometric constructions** 12. Make formal geometric constructions with a variety of tools and methods (compass and straightedge, string, reflective devices, paper folding, dynamic geometric software, etc.). *Copying a segment; copying an angle; bisecting a segment; bisecting an angle; constructing perpendicular lines, including the perpendicular bisector of a line segment; and constructing a line parallel to a given line through a point not on the line.* 13. Construct an equilateral triangle, a square, and a regular hexagon inscribed in a circle.
Exploring triangles and the triangle inequality	**CO: Prove geometric theorems** 10. Prove theorems about triangles. *Theorems include: measures of interior angles of a triangle sum to 180°; base angles of isosceles triangles are congruent; the segment joining midpoints of two sides of a triangle is parallel to the third side and half the length; the medians of a triangle meet at a point.*
Points of concurrency	**MG: Apply geometric concepts in modeling situations** 1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).★ 3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).★
Exploring angles formed by parallel and perpendicular lines	**CO: Prove geometric theorems** 9. Prove theorems about lines and angles. *Theorems include: vertical angles are congruent; when a transversal crosses parallel lines, alternate interior angles are congruent and corresponding angles are congruent; points on a*

	perpendicular bisector of a line segment are exactly those equidistant from the segment's endpoints.
Defining and classifying quadrilaterals Midpoint quadrilateral investigation	**CO: Prove geometric theorems** 11. Prove theorems about parallelograms. *Theorems include: opposite sides are congruent, opposite angles are congruent, the diagonals of a parallelogram bisect each other, and conversely, rectangles are parallelograms with congruent diagonals.*
Functions and transformations Reflections Rotations Dilations Translations	**CO: Experiment with transformations in the plane** 2. Represent transformations in the plane using, e.g., transparencies and geometry software; describe transformations as functions that take points in the plane as inputs and give other points as outputs. Compare transformations that preserve distance and angle to those that do not (e.g., translation versus horizontal stretch). 4. Develop definitions of rotations, reflections, and translations in terms of angles, circles, perpendicular lines, parallel lines, and line segments. 5. Given a geometric figure and a rotation, reflection, or translation, draw the transformed figure using, e.g., graph paper, tracing paper, or geometry software. Specify a sequence of transformations that will carry a given figure onto another. **CO: Understand congruence in terms of rigid motions** 6. Use geometric descriptions of rigid motions to transform figures and to predict the effect of a given rigid motion on a given figure; given two figures, use the definition of congruence in terms of rigid motions to decide if they are congruent. 7. Use the definition of congruence in terms of rigid motions to show that two triangles are congruent if and only if corresponding pairs of sides and corresponding pairs of angles are congruent. 8. Explain how the criteria for triangle congruence (ASA, SAS, and SSS) follow from the definition of congruence in terms of rigid motions.
Symmetry	**CO: Experiment with transformations in the plane** 3. Given a rectangle, parallelogram, trapezoid, or regular polygon, describe the rotations and reflections that carry it onto itself.

Tessellations Compositions of Transformations	**CO: Experiment with transformations in the plane** 5. Given a geometric figure and a rotation, reflection, or translation, draw the transformed figure using, e.g., graph paper, tracing paper, or geometry software. Specify a sequence of transformations that will carry a given figure onto another.
Using Matrices to Represent Transformations	**N-VM: Perform operations on matrices and use matrices in applications.** 8. (+) Add, subtract, and multiply matrices of appropriate dimensions. 9. (+) Understand that, unlike multiplication of numbers, matrix multiplication for square matrices is not a commutative operation, but still satisfies the associative and distributive properties. 12. (+) Work with 2 x 2 matrices as transformations of the plane, and interpret the absolute value of the determinant in terms of area.
Similarity	**SRT: Understand similarity in terms of similarity transformations** 1. Verify experimentally the properties of dilations given by a center and a scale factor: a. A dilation takes a line not passing through the center of the dilation to a parallel line, and leaves a line passing through the center unchanged. b. The dilation of a line segment is longer or shorter in the ratio given by the scale factor. 2. Given two figures, use the definition of similarity in terms of similarity transformations to decide if they are similar; explain using similarity transformations the meaning of similarity for triangles as the equality of all corresponding pairs of angles and the proportionality of all corresponding pairs of sides. 3. Use the properties of similarity transformations to establish the AA criterion for two triangles to be similar.

Appendix B

***Scaling Up* online professional development modules and module objectives**

Topic	Objective
Month 1: Geometric Constructions	Using Sketchpad's tools and construction commands, participants learn to construct dynamic sketches of common polygons and explore the relationship between their geometric properties and their construction.
Month 2: Geometric Tools	By focusing on a series of constructions of triangle centers, participants learn how to create custom tools in Sketchpad as well as action buttons and animations.
Month 3: Transformational Geometry	By focusing on a variety of activities involving reflections, translations, rotations, and dilations, participants investigate how to use Sketchpad to explore and apply transformational geometry.
Month 4: Geometric Proof	By focusing on activities involving polygons and circles that are the givens for formal proofs, participants explore how the dynamic nature of Sketchpad can support and reconceptualize traditional approaches to proof.
Month 5: Coordinate Geometry	By focusing on a variety of activities from algebra to trigonometry, participants learn how to use Sketchpad's coordinate geometry environment and dynamic function plotting capabilities.
Month 6: Dynamic Geometry	Participants focus on the concept of dynamic geometry as a unifying theme of the course and are introduced to the use of iteration in Sketchpad to create fractals.

Appendix C

Teacher Observation Notes

Name of teacher:

Location of class:

Subject observed:

Observer:

Date of observation:

Time:

In the space provided below please give a brief description of the lesson observed, the classroom setting in which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students (number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

Time	Description

Appendix D

Example of Field Notes

Teacher Observation Notes

Name of teacher: Rob

Location of class: School B

Subject observed: Geometry (Regular)

Observer: Researcher

Date of observation: 9/20/10

Time: 9:35 – 11:05am

In the space provided below please give a brief description of the lesson observed, the classroom setting in
which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students
(number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

Time	Description
9:35	Rob shares what will be going on the rest of the week (quiz Wednesday, 1/2 day Wednesday) Has students put progress reports in period folder Has students pull out specific sheet and write a converse inverse, and contrapositive for "If you like Peyton Manning, then you will be Mr. R's best friend" while he takes attendance
9:40	Rob: So you have your sheet out and notes out. We have to start with the hypothesis and conclusion of this statement. What's the statement S1: you like peyton manning Rob: Great…Now what is the conclusion S2: You are Mr. R's best friend Rob: Good, and you notice he didn't include "then" with the conclusion. So for our other three statements, we are just rearranging those two parts…We don't care right now about true or false, we are trying to get the patterns down right now. This is something we often see as easy, so we don't practice, and then we mess them up. I don't do them to torture you…(Keeps walking around the class

	while they right) Rob: Judgement day is upon us. Are you ready. 30 more seconds! (Students make comments off and on throughout) Rob: 10 seconds!
9:45	Rob: For the converse, what do we do to our original statement? S1: You take the 2nd part Rob: The conclusion S1: Yeah, and put it into the hypothesis thing Rob: Right so we are now doing Q then P. So how would you write that? S1: If you are Mr. R's best friend, then you like Peyton Manning Rob: So what you notice is that these pieces were in the original statement, but the conclusion has now become the hypothesis and the hypothesis has moved to the end…Any questions about the converse? Rob: Inverse is different. S2, so what happens? S2: So it's about not happening Rob: Right, the key word is "Not". Remember when I introduced, it was little squiggle p then little squiggle q where the squiggles were "not". So how would we write this S3: If you..Hold up, what was the original one? Rob: Use the one over there S3: Oh, so If you don't like PM then you are not Mr. R's best friend Rob: Good (writes on board)..I guess that's ok, we'll have to work on that. So we have taken the original, but negated each statement. We have negated, but the order stays the same Rob: Now how do we do the contrapositive? S4: Little squiggle q then little squiggle p Rob: Good, now we can use our terminology here…So the contrapositive is the converse of the inverse. Think of it being the most complex thing we have to do. So how would we write this? S4: If you are not Mr. R's best friend then you do not like PM Rob: Good (writes it on board) S4: He doesn't like Tom Brady S5: Because he sucks Rob: I cannot help it people like not as good players S4: (somethinga botu TB) Rob: I don't keep up with the news on TB but it does not lead to what we are doing…
9:53	S1: What does this have to do with math Rob: Now you are correct that PM has nothing to do with "our math", but we are doing this for a reason..Think back to last Friday.. S1: But that is English Rob: Yeah, there is a lot of writing, but what I am trying to do is help you move into deductive thinking…So we will begin using these examples to help warm

	you up so that when we move into Geometry, you will be ready
9:56	Rob: I am going ot put two statements on the board. You are going to have to figure out how many people meet each of these statements Writes 1) If you have braces, then you get a sucker 2) If you are a freshman, then you get a sucker Rob: Alright, there are two statements on the board (reads them) S1: I had braces Rob: Doesn't say had, it says have…Now what I want you to think this. Now let's determine how many suckers you get and how you know. But don't just think about yourself, look around the room. Smile so everyone can see. Rob: (Pulls out bag of suckers). So think through this and figure out. Some students are not happy because they don't meet either criteria. Rob hands out sheet. They talk, but not sure they are figuring this out.
9:59	Rob: Now if you or someone around you can have a sucker, then raise your hand…So S1, who gets a sucker around you? S1: This guy Rob: Why? S1: Because he's a freshman Rob: Great, so you knew he was a freshman, so he gets a sucker. Do you ? S1: No, because I'm not either Rob: Now S2 gets one because he's a freshman, but s1 does not. Does anyone? S3: S4 does because she's a freshman Rob: Do you? S3: Nope Rob: Why not? S3: because I don't have braces and I'm a sophomore Rob:Who else? S5: I have braces Few other students say they are freshman
10:03	Moves to document camera Rob: Now let's look at this sheet. Let's start with Deductive Reasoning. This is important because it uses facts, rules and definitions to make conclusions... Let's think back to Friday. We did inductive reasoning where we looked at past events…We are leaving that behind nad moving on to deductive reasoning. Now you were doing this with our short activity. You took the facts and determined who got a sucker…Now you do this all the time. If something is $10 and you have $5, can you buy it? S's: No Rob: No, we have set up rules for society that says what it takes to buy things…What we are doing is the law of detachment. What we have to understand is that every LofD has three facts…You get this nice statement here.

	Now over to the side of your paper, you might want to include this. So we start with our statement…Now we are going to need to actually test this, so we add a statement to test the hypothesis. Then you include the conclusion Law of Detachment 1)If p, then q 2) P is true 3) Q is true
10:08	Brings two students up to board Writes: If you have braces, then you get a sucker 2) S1 has braces S1 smile for us. S1 has braces. We had an if-then statement, p & q. The second statement says S1 has braces. Now some people try to cheat the system to get a sucker. let's look at S2. He does not have braces, so does he get a sucker? S's: no Rob: no, so we can't use the law of detachment because the statements have to be true…(moves on to example on paper notes)
10:13	Rob: No when look at line 1, we see something missing. What missing S1: the "then" Rob: Good so you are going to see that original statement in different ways because the English language is very verbose….
10:15	Rob: Now let's look at line 3 with the conclusion. Are these the same? S1: No Rob: why do you say that? S1: The if-then has a bunch of "woulds" Rob: Now if the meanings are the same but the tense is different, will that work if the statements stay true? Yes…
10:16	Hands out sheet with examples Rob: So we are going to work through these examples. I leave this table up here to help us work through the problems. So step 1: …On our example what is the hypothesis S: You like School Rob: S2, what is the conclusion S2: you are sad on Friday Rob: S3, now I know I'm hilarious, but please try to control you laughter. So help me out. Does line two match the hypothesis? S3: Yes Rob: Good, now S4, does line three match the conclusion? S4: Yes Rob: Good, so is this a valid statement or invalid? S's: Valid Rob: good, but they are not all valid

10:19	(moves to #2) Rob: S1, what is the hyp of this statement S1: sum of the measures of 2 angles is 180 Rob: Good, S2 what is the conclusion S2:.. Rob: Good, now S3 does our hypothesis and conclusion match with the next two lines? S3: no Rob: Why not S3: 90 and 95 do not equal 180 Rob: Great, so we recognize our hypothesis is not correct, so the statement is invald. Move on and try #3 on your own (gives a minute)
10:22	Rob: So S1, what is the hypothesis? S1: measure of angle A is less than 90 Rob: Does this match with line two? S1: Yes Rob: Why? That value is not 90? S1: The statement is supposed to be les than 90, which it is Rob: Great, so then we check our conclusion and line three. Are we valid? S's: Yes ….
10:24	Rob: So on the back, we have another set of statements to look at. Writes on board If you text in class, then you lose your phone If you lose your phone, then your parents are mad Rob: Now these two statements are related… But there is a follow up, which is that you losing your phone makes your parents mad….So if you text in class, then S1: your parents are mad Rob: Good (writes that on board)…Now we just used another law for deductive reasoning to make a statement. (brings two more students two board, gives each a marker). What I nee dyou to do first in red, underline the hypothesis of the first statement and label it P. Now S3, underline the conclusion of that statement in black and label it q. Now we look at the next statement. Now S4, before you drift off what is the hypothesis of that 2nd statement? S4: You lose your phone Rob: Great. Now S5, do you recognize that anywhere else? S4: it's the conclusion Rob: Great! Now instead of giving it a new letter, we just lable with the same letter Q. Now we have a statement "Your parents are mad" Has that shown up before? S's: No Rob: So we give it the letter R. Now what do you notice about statement three?

	Have we see the hypothesis before? S6: Yes, it was P in the first Rob: Good, now S7, what about the conclusion. Where does it show up? S7: The end of statement two
10:31	Rob: So we label it with R. So flip your paper over, and we are going to look at the Law of Syllogism. We are going to label them just like before. Now our Second statement begins where the last one ended. So with our example, you ended with losing your phone, statement two begins with losing your phone… Law of Syllogism 1) P -> Q 2) Q - > R 3) P -> R Rob: So now we are going to look at these examples. In the first statement of #4, identify the hyp and conclusion. The hyp is S's: You love numbers Rob: The conclusion is S's: You love math Rob: Good, now we move onto line two. Does "You love math" start line two S's: yes Rob: Good, and we have a new conclusion. So far we are good. Now, that last statement better take the P and put it with R. Does it do that? S's: Yes Rob: Great…Now look at the last two. One thing. What does it mean to be perpendicular? S1: they're side by side S2: They're right angles Rob: Good, so they are two lines that intersect to form right angles (draws on board)…So try these last two and see if you can determine if they are valid or invalid
10:37	Walks around looking at what students are doing. Goes to one student and works with her …Moves around more, tells one student to actually underline the p's and q's so that he can know they're doing more than guessing
10:39	Rob: Let's start with #6. Hypothesis is S's: My dog smells bacon Rob: and the conclusion S's: he goes crazy Rob: Alright, so in line two did the conclusion become the hypothesis? S's: Yes Rob: So now I need to see does the original hyp pair with the second conclusion? S: Yes

	Rob: So we have a valid statement
10:40	Rob: So let's look at #5. How many thought valid? (some raise) Invalid (some raise)... Line two throws off students because 1st q says "measure of the angle is 90", 2nd q says" 2 lines are perpendicular". Rob says by definition they are the same, so the first two lines are ok. However, does the third line do the correct pattern? S: No Rob: so the issue with this one is the final conclusion because it is brand new…This problem has a lot of terminology. Your quiz will not be as complex….Now your back page has problems that mix the two laws together…How can we just look at the problem and determine which law it is. S: The number of lines Rob: Well you are only given the first two lines, and you are going to provide the third line if valid. We can see the first line is the same. Now what is the difference in the 2nd line of each law. (Silence). Ok flip your paper over and look at the 2nd line of the law of D and the 2nd line of law of S. What is different? S: mumbles Rob: So the Law of S is an if then, but the Law of D is just a statement. So we know that the Law of S is going to be 3 if-then's while the Law of D will have only one If-then's and two lines of facts….Let's look at #7. So we start with the if then in line one. Next we have a statement. So mark the hyp and concl. Now we look at line two. Is is D or S? S: D Rob: So we need to check with D and see is the 2nd line the same as the hyp? S1 is nodding yes, but he's the only one showing brain activity. If you are not sure, then say that S2: I don't know S3: This one has actual points, which I'm not sure about Rob: So we have a general hypothesis now with a very specific statement. Are they saying the same thing? Well the first hyp we have a midpoint while line 2 says B is the midpoint of AC. They are saying the same thing, just it's being specific. The conclusion says the segments are congruent, so for line three we would know that AB is congruent to AC…. Rob Moves to #8 and marks P, Q, and R in the two lines. Explains why they are correct so far, then writes in the third line. Rob: Now try 9 – 13 for the last few minutes. If you need help, ask. This is your opportunity. I want to see underlining, and the P, Q, and R where needed. That is the easiest thing to start with…
10:55	Walks around, making suggestions, providing encouragement Students work silently individually Rob (to all): Remember it is not just underlining, it is also writing that third sentence if the statements so far are correct.

10:58	Students start talking, about half are talking about the problems. The other half are just chatting. Some actually do ask each other for help. At least one student gets up and explains a question
11:02	Rob: Tomorrow will continue in this chapter, but what we do tomorrow will not be on the quiz. What is in the homework will be on the quiz. Rob: Now you guys are doing really well with the law of syllogism, but you seem to be struggling with detachment. Don't overthink them…Your homework is p10 in the workbook, problems 1 – 7

Appendix E

Post-Observation Interview Questions for Observations One through Three

1. Tell me a little bit about how you planned for this lesson. Have you used this activity before? Was it shared with you from a colleague? Did you find it in a professional journal or on the internet?

2. Did you use any concepts from the Summer Institute or online professional development to help you prepare this lesson?

3. How do you feel the lesson went today? Did you accomplish your goals for the lesson?

4. How typical was this lesson for the students?

5. Did this lesson turn out different from what you planned? If so, in what ways?

6. Why did you decide to use technology for this lesson? Did it go as you planned? OR Why did you decide not to use technology for this lesson?

7. What do you think the students learned from this lesson, and what they still need to learn?

8. What challenges did you confront during this lesson? How might you deal with this challenge in future lessons?

9. What challenges did you confront in encouraging students to engage in the mathematical discourse?

10. Was there anything you would alter from the lesson if you were to re-teach this again?

11. During the lesson I noticed that you FILL IN WITH A PARTICULAR QUESTION OR ACTIVITY FROM THE LESSON THAT SEEMED INTERESTING. Can you tell me more about why you decided to FILL IN (ask that question, use that activity, pose that problem)?

12. Do you have any questions about upcoming lessons, concerns with technology, or any other items I may be able to assist you with today?

Appendix F

Post-Observation Interview Questions after Fourth Observation

1. Tell me a little bit about how you planned for this lesson. Have you used this activity before? Was it shared with you from a colleague? Did you find it in a professional journal or on the internet?

2. Did you use any concepts from the Summer Institute or online professional development to help you prepare this lesson?

3. How do you feel the lesson went today? Did you accomplish your goals for the lesson?

4. How typical was this lesson for the students?

5. Did this lesson turn out different from what you planned? If so, in what ways?

6. Why did you decide to use technology for this lesson? Did it go as you planned? OR Why did you decide not to use technology for this lesson?

7. What do you think the students learned from this lesson, and what they still need to learn?

8. What challenges did you confront during this lesson? How might you deal with this challenge in future lessons?

9. What challenges did you confront in encouraging students to engage in the mathematical discourse?

10. Was there anything you would alter from the lesson if you were to re-teach this again?

11. Number years teaching, and teaching geometry

12. How has personal knowledge in GSP and other technology changed

13. How has use of technology in class changed since last year and even throughout the semester?

14. Personal areas you wish to improve in teaching geometry with GSP/technology?

15. Specifics to address in next institute?

16. Do you have any questions about upcoming lessons, concerns with technology, or any other items I may be able to assist you with today?

Appendix G

IRB Exemption Approval Letter

North Carolina State University is a land-grant university and a constituent institution of The University of North Carolina

Office of Research and Graduate Studies

NC STATE UNIVERSITY

Sponsored Programs and
Regulatory Compliance
Campus Box 7514
2701 Sullivan Drive
Raleigh, NC 27695-7514

919.515.2444
919.515.7721 (fax)

From: Debra Paxton, IRB Administrator
North Carolina State University
Institutional Review Board

Date: August 25, 2010

Project Title: 1:1 Classrooms: A Study of Geometry Teachers' Practices

IRB#: 1219

Dear Mr. Dove:

The research proposal named above has received administrative review and has been approved as exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101. b.1, b.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: FWA00003429.
2. Any changes to the research must be submitted and approved by the IRB prior to implementation.
3. If any unanticipated problems occur, they must be reported to the IRB office within 5 business days.

Please provide your faculty sponsor with a copy of this approval letter.
Thank you.
Sincerely,
Debra Paxton
NCSU IRB

Appendix H

Participant Consent Form

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study: 1:1 Classrooms: A study of geometry teachers' practices
Principal Investigator: Mr. Anthony Dove Faculty Sponsor: Dr. Karen Hollebrands

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

What is the purpose of this study?
The purpose of this study is to better understand how to prepare teachers to use laptops and mathematics software for teaching Geometry in a 1:1 classroom environment.

What will happen if you take part in the study?
If you agree to participate in this study, you will be asked to (1) participate in three or four twenty-minute interviews during the school year, (2) allow the researcher to observe your mathematics classes three or four times and (3) allow the researcher access to the assignments that you submit during the on-line professional development course. The observations and interviews will be used to better understand how technology is used in the classroom and its effects on the classroom learning environment. Audio recordings may be made during interviews. Only the researcher will listen to entire recordings. Quotes from interviews and collected data may be used during educational conference presentations and might appear in research articles. In these instances, your name will be replaced with a pseudonym.

Risks
There are no risks associated with your participation in this project.

Benefits
As a participant in the various professional development opportunities, you have the opportunity to improve your content knowledge, knowledge in using technology, and knowledge in implanting the use of technology in teaching. The researcher plans to use the results of this study to enhance and improve future professional development opportunities in the use of technology in the mathematics classroom.

Confidentiality
The information in the study records will be kept confidential. Data will be stored securely on a password protected computer. No reference will be made in oral or written reports that could link you to the study. Your name can only be associated with your responses to interview questions by the researcher and will not be shared with anyone else, including other staff or administrators in your school district.

Compensation
For participating in this study you will not receive any compensation.

What if you have questions about this study?
If you have questions at any time about the study or the procedures, you may contact the researcher, Anthony Dove (amdove@ncsu.edu, 919-513-8577).

What if you have questions about your rights as a research participant?
If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514).

Consent To Participate and To Be Audiotaped
"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

Subject's signature________________________________ Date _________________

Investigator's signature____________________________ Date _________________

Consent To Participate But To Not Be Audiotaped
"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled." I agree to participate in all aspects of the study, but to not be included in the audio recordings.

Subject's signature________________________________ Date _________________

Investigator's signature____________________________ Date _________________