

**Teaching and Learning Algebra 1 via an Intelligent Tutor System:
Effects on Student Engagement and Achievement**

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Abstract

This study investigated the implementation and outcomes of blended learning that integrated Apangea Math, an online intelligent tutor system (ITS), with face-to-face instruction for the teaching and learning of Algebra 1. It took place in a Title I urban high school where 75 ninth grade students and their teachers enacted the blended learning program for one semester. Students from the same high school who received face-to-face instruction alone during a previous semester served as a comparison group. Flow theory was proposed as an explanation for why the ITS program was expected to increase student engagement and improve student achievement.

This quasi-experimental, mixed methods study collected data via student assessments, surveys, observation forms, questionnaires, and meeting notes. Fidelity of implementation was rated based on four components: adherence, exposure, quality of delivery, and participant responsiveness. Challenges encountered and practices used when implementing the program were characterized as first-order (external) or second-order (internal) and were analyzed to reveal themes.

A mixed ANOVA conducted on assessment data revealed a significant interaction effect between time (pre or post) and group (intervention or comparison) on achievement, $F(1,157) = 5.25$, $p < .05$, partial $\eta^2 = .032$. This indicated that the intervention group's achievement gains ($M = 9.45$ points) were significantly greater than the comparison group's gains ($M = 4.65$ points). Furthermore, instruction that included the use of Apangea Math significantly improved achievement for students whose initial skill level was below basic, but it did not change achievement significantly for those

whose initial skill levels were higher (basic, proficient, or advanced). Analysis of data by teacher suggested that Apangea Math usage contributed toward the closing of achievement gaps.

Teachers' ratings, classroom observations, and questionnaire responses indicated that many students tended to be engaged in the online tutorial program; however, surveys showed no significant changes in students' attitudes towards learning mathematics after they experienced blended learning for one semester. Two prevalent second order challenges were "lack of time" and "disbelief in the program," while "establishing protocols" was the most frequently mentioned beneficial practice. Implications for administrators and teachers are discussed, and future research is recommended.

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Chapter 1

Introduction

Online learning has the potential to be a disruptive force that will transform the factory-like, monolithic structure that has dominated America's schools into a new model that is student-centric, highly personalized for each learner, and more productive, as it delivers dramatically better results at the same or lower cost (Horn & Staker, 2011, p. 2).

Over the past few decades, technology has become ubiquitous in our society (Chen, Lim, & Tan, 2011); consequently, it has influenced teaching and learning. There are numerous computer programs available that claim to enhance instruction, and students tend to rate lessons that use computers as highly engaging (Guerrero, Walker, & Dugdale, 2004; Scherer, 2002). Studies of computer technology used for instruction demonstrate that it can have a positive impact on teaching and learning (Harmon, 2011; Huffmyer, 2008; McClure, 2006; Mo, 2011). Recurring themes in these studies suggest that computer programs used appropriately increase student engagement, provide opportunities for teachers to differentiate instruction, and improve student achievement. In light of these themes, this study examines the implementation of an online computer program as a routine portion of classroom instruction and its impact on student engagement and achievement in mathematics.

Statement of the Problem

It is widely recognized that student engagement is a key ingredient for academic success for learners of all ages. “Student engagement or motivation is key to learning. No matter how much work the teacher does, if the student doesn’t work, the student doesn’t learn” (Reigeluth, 2011, p. 25). Students’ engagement in school tends to decline starting in middle school, and students who are disengaging may begin to have poor attendance rates, misbehave, or fail courses (Balfanz, Herzog, & Iver, 2007). Teaching discrete disciplines in compartmentalized time periods, as is typical in Western high schools, fragments subjects and obscures the interconnections among different forms of knowing. This results in subjects that do not seem relevant to students; students’ lack of understanding about the more extensive relationships between subjects tends to lead to decreased levels of engagement (Gallant, 2011). In school, these disconnected lessons may not seem relevant, and teacher-centered approaches used by many U.S. teachers leave students with no way to exercise any control over their learning. Students tend to lose interest in learning when they find themselves in classroom conditions where they must rely on teachers to select and deliver specific course content, the lessons seem irrelevant, and there is little or no opportunity for them to take control of their learning. “Often kids are put in a dependent state in school; they are not supposed to take any initiative except in what the teachers want them to do” (Scherer, 2002, p. 17).

My experience teaching in Grades 6 – 9 exposed me to this phenomenon of student disengagement, and seeing students become apathetic about their education prompted me to look for ways to re-engage students and motivate them to learn. To

combat disengagement, schools can reform their instructional programs emphasizing research-based instructional strategies in an effort to provide active, engaging pedagogies (Balfanz, et al., 2007). Student engagement tends to increase when students perceive lessons to be relevant, and when they have some control over their learning activities (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003). Furthermore, providing opportunities for students to experience success and tailoring lessons to balance academically challenging tasks with support fosters student engagement and academic success (Schussler, 2009).

Student achievement in mathematics has been an area of concern in America (National Mathematics Advisory Panel, 2008), and standards for mathematics education have been established and revised in order to address this concern (Common Core State Standards Initiative, 2010a; National Council of Teachers of Mathematics, 2000). The importance of learning Algebra, typically regarded as a gatekeeper course for higher level mathematics, has become a topic of particular interest in the mathematics education community (Capraro & Joffrion, 2006; Ladson-Billings, 1997; Stein, Kaufman, Sherman, & Hillen, 2011; Wu, 2001).

Because algebra has come to be regarded as a gatekeeper course—those who successfully pass through will keep going while those who don't will be permanently left behind—the high failure rate in algebra, especially among minority students, has rightfully become an issue of general social concern. (Wu, 2001, p. 1)

Literature suggests that technology, used appropriately, can provide learning opportunities that improve student engagement and achievement (Ellington, 2003; Guerrero, et al., 2004; Harmon, 2011; Huffmyer, 2008; Mo, 2011; Scherer, 2002). However, educational technology is often described enthusiastically with too little evidence of improved learning provided (Fletcher, 2011); therefore, additional research is needed regarding the effects of educational technology. There is a particular need in the K-12 environment to study the effects of blended learning, which combines face-to-face instruction with online instruction (Chen, et al., 2011; Means, Toyama, Murphy, Bakie, & Jones, 2010; Patrick, 2011).

Purpose and Significance

The purpose of this study is to examine the effects of an intelligent tutor system (ITS) on students' engagement and achievement in Algebra 1. This study also describes the process of implementing the ITS program and documents both the challenges encountered and the teaching practices used. The study took place during the spring semester of 2012 in an urban high school that had been performing below average on high-stakes state assessments and not making adequate yearly progress in mathematics as defined by the No Child Left Behind (NCLB) Act ("No Child Left Behind Act," 2001). Title I, which provides federal funds for programs in high poverty schools, funded this ITS program as part of a school improvement grant.

This innovative intervention program provided Algebra 1 students with the use of wireless tablet computers for math class and access to an ITS program, Apangea[®] Math. Apangea Math's tutorial model is based on research conducted by the U.S. Air Force

Research Laboratory and the National Science Foundation, where the program was developed as a cognitive tutor based on appropriate thinking processes and interventions that help students who struggle with learning mathematics (Apangea Learning, 2011). Apangea Math uses artificial intelligence, which differentiates it from many other computer-assisted instruction programs enabling it to adapt and customize each student's learning experience. Traditional computer-assisted instruction programs use predefined branching sequences; whereas, ITS programs such as Apangea Math determine what feedback students will receive and subsequent practice problems based on production rules (D. L. Johnson, 2005). Based on cognitive psychology, production rules are the if-then rules that can be used to represent all cognitive functions and to explain how people organize knowledge. The process of following these rules enables Apangea Math to consider multiple solutions, diagnose student skills, customize remediation, and ensure that the challenge level presented to each student closely matches his or her individual skill level.

This study has the potential to impact students, teachers, administrators, and the larger educational community. Providing administrators with information about program effectiveness may inform their decisions about the use of this type of program in the future. Describing the implementation of this blended learning curriculum may provide teachers with practical information about the process of integrating technology into their teaching to enhance pedagogy (Mishra & Koehler, 2006; Mishra, Koehler, & Kereluik, 2009; Niess et al., 2009; Schmidt et al., 2009b). Teachers may also benefit from learning about how their role in blended learning compared to traditional instruction is expected to

shift from knowledge transmitter to facilitator or coach (Prensky, 2011; Reigeluth, 2011; Zhu, 2010). Students may be impacted by this study because if it is revealed that the intervention group experienced greater achievement gains than the comparison group, than the probability of future classes using and benefiting from technology in this way may increase. Furthermore, this study has the potential to impact the larger educational community by contributing to the growing body of knowledge about the use of technology in education.

Research Questions

The primary focus of this study is to determine if the use of a blended model of instruction, integrating Apangea Math with face-to-face instruction, yields different student outcomes than a curriculum consisting entirely of face-to-face instruction. The secondary focus of this study is to describe the implementation process of this new blended instructional program in an effort to determine why improved student outcomes were or were not realized. Therefore, the following research questions were investigated:

1. How does student achievement in Algebra 1 differ based on instructional program?

Related sub-questions:

- How does student achievement in each of Tennessee's mathematics content standards for Algebra 1, (a) mathematical processes, (b) number and operations, (c) algebra, (d) geometry and measurement, and (e) data analysis, statistics, and probability differ based on instructional program?

- How do student achievement gains differ by instructional treatment based on students' initial skill levels?
2. How does student engagement in mathematics change after students experience blended learning with Apangea Math?

Related sub-questions:

- How does each construct of student engagement, (a) learning goal, (b) task value, (c) self-efficacy, and (d) self-regulation differ after exposure to Apangea Math?
 - How do teachers, classroom observations, and students rate the engagement of students in Apangea Math?
3. How well was Apangea Math implemented in relation to how it was intended to be implemented?

Related sub-questions:

- What challenges do teachers encounter, and what practices do they use when implementing Apangea Math?
- What relationships exist between implementation fidelity and achievement?

Limitations

This study contains a few conditions that were not within my control that had the potential to influence its outcome. First, the ethnicity and socioeconomic status of the student-participants was not diverse; approximately 90% of the student body was African American, and over 85% of the students qualified for free or reduced lunch. Therefore,

the findings of this study may not be generalizable to students from other demographic backgrounds.

Additional potential limitations revolved around the actual instruction that was implemented during this study. Differences, other than the intended intervention, may have occurred which could impact student outcomes. For example, teachers were expected, as a side-effect of the implementation of blended curriculum, to increase the differentiation of face-to-face instruction; thus, the adoption of more differentiation practices may have affected students' attitudes and achievement. Another teacher behavior that may have impacted the study stemmed from the pressure of high-stakes tests. The need to prepare students for the end-of-course (EOC) exam may have caused teachers to redirect students towards online lessons that addressed the known content of the test, rather than letting artificial intelligence provide personalized online instruction where challenges of assigned tasks closely match students' skill levels. Another potential limitation was technology. This was a new program that relied on the smooth operation of many new wireless devices that were dependent on adequate network resources; therefore, experiencing technical difficulty could have influenced outcomes. These types of unplanned experiential differences may have posed a selection history threat to internal validity.

Finally, some possible limitations were present in the measurement of the criteria of interest in this study. The pre-test achievement scores of the intervention group and the comparison group were not the same; thus, absolute scores were of limited use and change-over-time was more informative. Furthermore, the possibility of an aptitude

treatment interaction (ATI) could contribute to contradictions in some analyses; specifically, the instructional programs may affect students' with different ability levels differently. The student engagement surveys were dependent on students' perceptions, and they were only administered to the intervention group (pre and post) because the comparison group consisted of students who took Algebra 1 prior to the study, thus the student engagement survey data was limited to one-group design analyses.

Delimitations

There were other conditions that were within my control that may have influenced the outcome of this study. I chose to conduct this study in a school where I taught full-time two years ago and where I was currently employed part-time, working 10 to 15 hours per week, as an Algebra 1 consultant. A school improvement grant funded my position and school administrators asked me to coordinate the implementation of Apangea Math and gather evidence regarding the effectiveness of the program. In this position, I potentially influenced teachers since I met with them about three times per month to (a) provide professional development training about the implementation of Apangea Math, (b) outline protocols to establish structure and consistency regarding lessons and grading, and (c) analyze reports of student progress data. I worked with eight Algebra teachers whose students had access to Apangea Math. Four of these teachers had classroom sets of wireless tablet computers, and they taught the ninth grade Algebra 1 students who were the participants in this study. The additional four teachers did not have wireless tablet computers, they taught Algebra 1 to students who were in tenth or eleventh grade or were in special education, and they were not part of this study. My

working relationship within the school may be viewed as creating a bias that is considered limiting to the study. I served as a resource that guided teachers through the learning curve that is inevitably part of navigating any new program. Furthermore, my persistent requests to the high school's instructional technology coordinator and the school district technology personnel led to solutions when technical problems were encountered in the early days of the implementation; thus, my involvement supported the implementation of the blended learning program. However, it is important to acknowledge that my presence and influence may have contributed to the outcomes of this study.

Assumptions

In this study, some of the data collected came from students' responses to a survey; thus, it was assumed that students responded honestly about their feelings and attitudes towards mathematics. Other data came from teachers' reflections on weekly forms; therefore, it was also assumed that teachers honestly reported the events that occurred during the implementation of the program.

Definitions

Apangea Math: "one-student-to-one-teacher differentiated math instruction through a unique integration of proprietary tutoring technology and live, online certified teachers. As a web-based solution, Apangea Math can be accessed from any computer with an internet connection – ensuring students can learn math anytime, anywhere" (Apangea Learning, 2011, para. 1).

Aptitude-Treatment Interaction (ATI): “ATI is said to be present when for some group of persons an aptitude variable shows a different relation to an outcome variable in one treatment than it does in another” (Snow, 1991, p. 206).

Artificial Intelligence (AI): “the simulation of human intelligence processes by machines, especially computer systems. These processes include learning (the acquisition of information and rules for using the information), reasoning (using the rules to reach approximate or definite conclusions), and self-correction” (TechTarget, 2000, para. 1). “AI mimics human thought and cognitive processes to solve complex problems” (D. L. Johnson, 2005, p. 17).

Blended Learning: “any time a student learns at least in part at a supervised brick-and-mortar location away from home and at least in part through online delivery with some element of student control over time, place, path, and/or pace” (Horn & Staker, 2011, p. 3).

Computer Assisted Instruction (CAI): “employs conditional branching after assessing the student’s response, either looping the student through built-in remediation or advancing the student to the next problem. Developers construct the branches in advance.” (D. L. Johnson, 2005, p. 17). CAI is typically not capable of recognizing students’ misconceptions or errors.

Content knowledge (CK): “knowledge about actual subject matter that is to be learned or taught” (Mishra & Koehler, 2006, p. 1026).

Fidelity of implementation: “Fidelity of implementation is the delivery of content and instructional strategies in the way in which they were intended to be delivered” (E. Johnson, Mellard, Fuchs, & McKnight, 2006, p. 5.2).

Flow Theory: A theory proposed by Mihaly Csikszentmihalyi in 1975 that describes flow as the mental state of people who are motivated, cognitively efficient, and happy (Liao, 2006).

Intelligent Tutor System (ITS): “These applications use AI software technologies and cognitive psychology models to provide one-on-one instruction. They evaluate student performance, assess the student knowledge and skills, provide instructional feedback, and select appropriate next exercises for the student” (D. L. Johnson, 2005, p. 17).

Pedagogical content knowledge (PCK): “the particular form of content knowledge that embodies the aspects of content most germane to its teachability...the ways of representing and formulating the subject that make it comprehensible to others” (Shulman, 1986, p. 9).

Pedagogical knowledge (PK): “the methods and processes of teaching and includes knowledge in classroom management, assessment, lesson plan development, and student learning” (Schmidt, et al., 2009b, p. 125).

Student engagement: “a psychological process, specifically, the attention, interest, investment, and effort students expend in the work of learning” (Marks, 2000).

Technology knowledge (TK): “knowledge about various technologies, ranging from low-tech technologies such as pencil and paper to digital technologies such as the

Internet, digital video, interactive whiteboards, and software programs” (Schmidt, et al., 2009b, p. 125).

Technological content knowledge (TCK): knowing how to use specific technology to create new representations for content that can improve students’ understanding and practice of concepts (Schmidt, et al., 2009b).

Technological pedagogical knowledge (TPK): knowing how technologies can be used in teaching and how teaching can be changed by the use of technology (Mishra & Koehler, 2006; Schmidt, et al., 2009b).

Technological pedagogical content knowledge (TPACK): “the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face” (Mishra & Koehler, 2006, p. 1029).

Ubiquitous Computing: “refers to emerging learning environments in which one student has multiple Internet-connected devices available, and the ability to learn in a variety of locations” (Chen, et al., 2011, p. 21).

Organization of the Study

This study is organized into five chapters. Chapter 1 introduced the study by describing the problem of student-disengagement and the potential for a technology-based instructional program to engage students. Next, the purpose and significance of the study was explained. Further, the research questions were posed, and limitations,

delimitations, and assumptions were presented. Chapter 1 ended with definitions of key terms that are used in this study.

Chapter 2 is a literature review which begins with a discussion about the educational needs of the post-industrial age, the rising importance of Algebra as a *gatekeeper*, and a brief history of educational technology. Then, the importance of giving careful consideration to the pedagogical affordances of technology is examined followed by a review of relevant research. Next, Flow Theory is described as an explanation supporting why ITS programs are expected to improve student engagement. Finally, the rise of blended learning in K-12 education is outlined, including how it impacts students' and teachers' roles and the knowledge teachers need to teach with technology. Chapter 2 concludes with a discussion of teaching practices used and challenges that can be expected when implementing online learning.

Chapter 3 delineates the procedures planned for this study. A general description of the Apangea Math program is followed by a description of the participants in the intervention group and the comparison group. Then the constructs of interest and the instruments used to gather data are presented. Chapter 3 ends with the design of the study and proposed analyses.

Chapter 4 presents the results of the study, beginning with achievement measured by summative and formative assessments. Student engagement is studied from the standpoint of student surveys, teachers' and classroom observation ratings, and questionnaires. Program processes are described in terms of protocols adopted, fidelity with which the program was implemented, challenges encountered, and practices used.

Chapter 4 ends with an examination of correlations between the implementation factors and outcomes to determine how processes may have contributed to outcomes.

Chapter 5 discusses confirmed findings, and reflections on findings lead to lessons learned. Chapter 5 concludes with implications for administrators and teachers and recommendations for additional research.

Chapter 2

Literature Review

The educational system is evolving in response to changes in the economy and technological developments. Overlapping and interconnected aspects of content, pedagogy, and technology are shaping emerging models of learning. In the context of this study, the content is Algebra 1, which is now required in many states for all students including those who lack prerequisite mathematical knowledge. The pedagogy employed is a blended learning model which combines typical face-to-face instruction with the use of computer technology, specifically, Apangea Math. In addition to examining content, pedagogy, and technology, this literature review explores the impact of online learning on students and teachers and makes a claim that Flow Theory explains student engagement with computer-based instructional technology.

Background

The problem of disengagement may be directly related to how Western society views education and structures the educational system (Gallant, 2011; Reigeluth, 2011). The current education system was designed in the industrial age, when not everyone needed to be highly trained because the main form of work was manual labor. Furthermore, Western society takes a mentally rationalized approach by which schooling is externally driven, relying on systematized educational programs and high-stakes testing (Gallant, 2011). This educational system can be described as “a reflection of Western cultural consciousness that values efficiency, benchmarking, compliance, skills,

and material outcomes, but not processes... The hidden cost to this overemphasis is disengagement” (Gallant, p. 350).

The mentally rationalized, industrial-age educational system is not well suited for learning (Gallant, 2011; Reigeluth, 2011). Instead, it focuses on sorting students, which is evident in the predominant use of norm-referenced tests; this sorting serves an industrial economy by determining which students become professionals and which become laborers (Reigeluth, 2011). In this system, students are taught predetermined amounts of content over specific periods of time, often leaving faster learners bored and slower learners without enough time to master the content (Reigeluth, 2011); the context is fragmented and learning flow is inhibited (Gallant, 2011).

Now, in the post-industrial era, what is needed is an educational system focused on learning to meet the demands of a knowledge-based economy (Zhu, 2010). In a vision of a post-industrial paradigm of instruction, students work in small groups on problem-based projects, and whenever new concepts or skills are needed, the students receive computer-based individualized instruction, practice, and immediate feedback until they meet the criterion for mastery of the new content (Reigeluth, 2011). In this way, computer programs can play a role in the post-industrial educational paradigm as they enable students to learn content at their own pace (Chen, et al., 2011; Horn & Staker, 2011; Patrick, 2011; Reigeluth, 2011).

Algebra Content

In our knowledge-based economy, algebra is seen as the gatekeeper to high-level mathematics and high-paying career opportunities (Capraro & Joffrion, 2006; Ladson-

Billings, 1997; Stein, et al., 2011; Wu, 2001). However, some students, particularly those in predominantly African-American schools, have historically had less rigorous mathematics programs and fewer opportunities to take gatekeeper courses such as algebra (Ladson-Billings, 1997). Consequently, policies have been enacted to mandate that all students take Algebra at eighth or ninth grade (Stein, et al., 2011). These universal algebra policies eliminated the problem of inequities experienced by some students who were prepared to take algebra but did not have access to it; however, these policies simultaneously created the new problem of students who are not prepared to take algebra being required to take it. Stein et al. (2011) explained that underprepared students do not do well in regular algebra classes; they need additional instructional time or remedial interventions to improve their chances for success. Regardless of the challenges experienced by underprepared students, some in the education community have pushed in recent years for all students to take algebra in eighth grade (Common Core State Standards Initiative, 2010a, 2010b; Confrey & Krupa, 2010; National Mathematics Advisory Panel, 2008; Seeley, 2005).

In preparation for Algebra 1, students' understanding of many mathematical concepts needs to be developed. In order for students to be appropriately prepared to take a formal Algebra 1 course, it is necessary to teach algebraic concepts throughout elementary and middle school (Common Core State Standards Initiative, 2010a, 2010b; Seeley, 2005; Silver, 2000). Arithmetic is the foundation for algebra because algebra is generalized arithmetic (Carpenter, Franke, & Levi, 2003; Wu, 2001). Basic arithmetic and fluent computation with numbers are essential for learning to develop proficiency at

the symbolic manipulation that is integral to algebra (Loveless & Coughlan, 2004; Wu, 2001). Understanding of the meaning of the equal sign as representing a relation between two values that are the same is a key concept that supports algebraic thinking (Carpenter, et al., 2003; Matthews, Rittle-Johnson, McEldoon, & Taylor, 2012). A common misconception about the equal sign is that it indicates an immediate need to compute the operation that was presented just prior to the equal sign; for example, many students in first to sixth grade would fill in the blank in $8 + 4 = __ + 7$ with a 12 instead of the correct response of 5 (Carpenter, et al., 2003).

The idea that many mathematical concepts are considered prerequisites to learning algebra is supported by a statement in *Foundations for success: The final report of the National Mathematics Advisory Panel* (2008), “The coherence and sequential nature of mathematics dictate the foundational skills that are necessary for the learning of algebra” (p. 18). For example, conceptual understanding about fractions prepares students for developing algebraic concepts (G. Brown & Quinn, 2006, 2007; Cheng, 2010; National Mathematics Advisory Panel, 2008). The properties of arithmetic (e.g., identity properties of addition and multiplication, commutative, associative, and distributive properties) are also needed to generalize arithmetic which leads to algebraic statements that are always true for all numbers (Ding & Li, 2010; Tent, 2006; Wu, 2001). Additionally, students need to develop skill at translating words into mathematical symbols prior to taking a formal algebra course (Capraro & Joffrion, 2006). Students need to gradually bridge the span between quantitative relationships with numbers in arithmetic to generalized relationships with symbolic notation in algebra (G. Brown &

Quinn, 2007; Seeley, 2005; Silver, 2000; Wu, 2001). When students gain experience in the generalization of patterns, they build a foundation for thinking algebraically (Ellis, 2011; Herbert & Brown, 1997).

Clearly, Algebra 1 is widely viewed as a gatekeeper to student success in our current educational system, and students need prerequisite mathematical content knowledge in order to be successful in Algebra 1. Therefore, there is a need to provide personalized instruction to address the many different learning gaps that underprepared Algebra 1 students may have. The need that students have to learn different concepts at their own pace can be met with the use of computer-based instructional technology (Chen, et al., 2011; Horn & Staker, 2011; Patrick, 2011; Reigeluth, 2011).

Pedagogical Affordances of Technology

Instructional technology has been developed to aid in the teaching and learning of many subjects including mathematics. The use of technology varies widely and some uses may be more pedagogically appropriate than others. The technology principle stated in the NCTM Principles and Standards (2000) clearly recommended that all students have access to technology when learning mathematics; however, it further indicated that teachers are responsible for making decisions concerning how to use technology in ways that enhance students' mathematical thinking.

For the past few decades, educational organizations have expressed the need to focus on pedagogy in association with the use of technology. For example, a textbook, currently titled *Instructional Technology and Media for Learning*, has been through 10 revisions in the past 30 years (Smaldino, Lowther, & Russell, 2011). This book has

helped guide educators in considering students' needs as they integrate technology into instruction. The book focuses on "the ASSURE model as a process for designing learning experiences - Analyze learners; State standards and objectives; Select strategies, technology, media, and materials; Utilize technology, media, and materials; Require learner participation; Evaluate and revise" (Smaldino, et al., 2011, p. 44). In the last few years, the International Society for Technology and Education (ISTE) has published National Education Technology Standards for Teachers (NETS-T) and for Students (NETS-S) regarding the usage of technology in education (International Society for Technology in Education, 2008a, 2008b). Furthermore, the Association of Mathematics Teacher Educators (AMTE) has released the Mathematics TPACK (Technological Pedagogical Content Knowledge) Framework (Association of Mathematics Teacher Education, 2009) to elaborate on the NET-T specifically for teachers of mathematics. These types of models provide evidence that educators have shifted their thinking about technology from acquisition to pedagogical uses; their focus is no longer on the technology itself because education is not about the technology, it is about how the technology enhances teaching and learning (Chen, et al., 2011). These models provide standards that are important because simply employing technology in classroom instruction is not a guarantee that it will facilitate learning (Ellington, 2003; Guerrero, et al., 2004). Comma-Quinn (2011) made this point well saying, "The use of new technologies alone cannot ensure learning without a strong pedagogical rationale and appropriate integration with the course" (p. 219).

There are times when new technology may be used inappropriately in education. Technology use does not provide pedagogically appropriate instruction if it consists of accessing material that is as static as books or as traditional as instructor-led lecture-style lessons (Patrick, 2011; Zhu, 2010) since that type of content does not provide students any opportunity to be interactive. Furthermore, technology may be used to circumvent thinking to just get answers quickly in the absence of conceptual learning (Roll, Aleven, McLaren, & Koedinger, 2011). For example, consider a scenario where the objective of a mathematics lesson is to understand exponential functions and how they are used in the context of computing compound interest. A teacher may find the following two computer applications involving the concept of computing interest and need to decide which is more appropriate for the lesson. The first application, which is found on the Moneychimp website (Moneychimp, n.d.), calculates interest for users. The second application, which is found on the Illuminations website (National Council of Teachers of Mathematics, 2012) guides users through an investigation about computing interest. The Moneychimp application is an example of a functional use of technology which enables students to determine the value of an account at a future date without any understanding of the underlying mathematics. The Moneychimp application, despite its ability to provide accurate answers, would not be pedagogically appropriate for this lesson. On the contrary, the Illuminations application is an example of a pedagogical use of technology which provides an opportunity for students to develop conceptual understanding about the mathematics involved in calculating compound interest.

If technology is not used appropriately, a pedagogical affordance of online learning that may not be realized is personalized instruction, which enables students to learn at their own pace. This could happen because “there is a significant risk that the existing education systems will co-opt online learning as it blends it into its current, antiquated model” (Horn & Staker, 2011, p. 12). Recognizing that the choice of computer programs and the manner in which they are implemented impacts the effectiveness of using computers to foster learning, the need to research the efficacy of specific computer programs becomes clear.

Because this study involves using technology to enhance mathematics instruction, it is relevant to review pedagogical considerations related to using technologies such as calculators, computer programs, and the internet when developing lessons and instructional programs (Comas-Quinn, 2011; Confrey & Krupa, 2010; Ellington, 2003; Guerrero, et al., 2004; Lucas & Cady, 2012; National Council of Teachers of Mathematics, 2005, 2008). Calculators have been available for routine classroom use for quite a few decades, and professional mathematics organizations, researchers, and mathematics educators have evaluated calculator usage in K-12 classrooms. In particular, the NCTM indicated that calculators need to be used effectively in order to enhance students’ understanding; specifically, teachers’ appropriate use of this technology should help students develop deeper mathematical understanding, not replace that understanding (National Council of Teachers of Mathematics, 2005). Ellington’s (2003) meta-analysis of studies about the effects of calculator usage with K-12 students supported the notion that pedagogical uses for technology were more beneficial than

functional uses of technology. Ellington clarified that “pedagogical use refers to using the calculator as an essential element in the teaching and learning of mathematics; functional use means that it was used only in activities such as computation, drill and practice, and checking paper-and-pencil work” (p. 438). Thus, it is not appropriate to use calculators when the main objective of an activity is developing computational skills, but calculators are appropriate when students are engaged in activities that involve searching for patterns, exploring concepts, developing number sense, promoting creativity, and solving problems that require computations that are more complex than the students are prepared to do without the use of technology (Reys, Lindquist, Lambdin, Smith, & Suydam, 2004; Van-de-Walle, Karp, & Bay-Williams, 2010). Teachers can use calculators to provide activities that help students develop their mathematical understanding about concepts such as place value, the meaning of operations, and estimation, and it is each classroom teacher’s responsibility to select appropriate activities and times for using calculators for instruction (Lucas & Cady, 2012; Reys, et al., 2004; Van-de-Walle, et al., 2010).

The routine use of computers in classrooms has become progressively more widespread in the last two decades and, like calculators, computer programs have the potential to facilitate learning when they are used appropriately. When technology is used pedagogically it can benefit students’ attitudes about learning, self-efficacy, engagement, academic achievement, and conceptual understanding (Guerrero, et al., 2004).

It is widely accepted that active learning increases student engagement and promotes learning more than passive learning (Confrey & Krupa, 2010; National Council of Teachers of Mathematics, 2000; Scherer, 2002; Shernoff, et al., 2003), and one curriculum option for providing active learning is employing interactive computer programs that prompt students to engage in learning activities (Chen, et al., 2011; Mupinga, 2005). With student-centered, personalized programs, learners gain control over their learning as they interact with the technology and progress at their own pace (Horn & Staker, 2011; Patrick, 2011).

Computer programs can also facilitate differentiation by generating timely information enabling teachers to make data-driven decisions about instruction (Butler, 2010; Horn & Staker, 2011; Patrick, 2011). Instructional technology can be adapted to meet students growing skills (Chen, et al., 2011) by teachers assigning different applications to accommodate students' needs or adaptive programs automatically adjusting challenges to match students' demonstrated skills.

Now that technologies have become portable and we have entered an era of ubiquitous computing, learners have the flexibility to conveniently engage in technology-based learning that extends beyond the school day (Butler, 2010; Chen, et al., 2011; Mortensen, 2011). Students are supported by the many computer programs that provide explanations, hints, and immediate feedback (Horn & Staker, 2011). Finally, well-designed programs provide competency-based learning pathways and opportunities for students to experience and enjoy incremental success (Patrick, 2011).

Evidence of Computer Technology's Impact on Student Engagement

Educators and researchers have reported an improvement in engagement when students have the opportunity to learn with computer technology that is thoughtfully integrated into their education (Fleisher, 2006; Harmon, 2011; Huffmyer, 2008; D. L. Johnson, 2005; McClure, 2006; Mo, 2011; Scherer, 2002). Studies by Harmon (2011), Huffmyer (2008), McClure (2006), and Mo (2011) all reported improved student engagement, but they differed based on grade level, subject, and technology platform. The grade levels involved included middle school (McClure, 2006), high school (Harmon, 2011), and college (Mo, 2011). The subjects taught were English (Harmon, 2011), mathematics (Huffmyer, 2008; McClure, 2006), and accounting (Mo, 2011). All of these studies utilized computer-based technologies but used different platforms and programs; namely, iPad[®] with applications and internet (Harmon, 2011), Texas Instruments[®] Navigator classroom learning system and graphing calculators (McClure, 2006), Blackboard[®] Vista and internet (Mo, 2011), and the online ITS, Apangea Math (Huffmyer, 2008).

These studies varied in what pedagogical affordances they credited as benefiting student engagement and learning. The researchers commonly cited instant feedback as a major pedagogical advantage provided by technology (Harmon, 2011; McClure, 2006; Mo, 2011). Technology was also lauded for enabling teachers to differentiate instruction (Harmon, 2011; Huffmyer, 2008; McClure, 2006). Technology's ability to individualize instruction and provide personalized tutoring, helped students build confidence (Huffmyer, 2008; McClure, 2006). The interactive nature of the technology (McClure,

2006) and the flexibility for students to work at their own pace (Huffmyer, 2008; Mo, 2011) also supported student engagement. These studies are described in greater detail in the following paragraphs in order to demonstrate how student engagement can be increased when implementing computer-based technologies in a variety of educational contexts.

A school district in Ohio, where the middle schools were not making adequate yearly progress (AYP) in mathematics, set two goals: (a) to make AYP and (b) to increase student engagement in math classes (McClure, 2006). McClure explained how the district math coach wanted to implement a program with interactive, investigative lessons. As a result, grant funds were secured and used to integrate the Texas Instruments Navigator Classroom Learning System and graphing calculators into three of their four middle schools in 2004-05; the fourth middle school served as a control group. The treatment group participants each received a graphing calculator which was connected to the teacher's computer. Teachers were then able to send assignments, quizzes, and instant polls directly to students' devices. This enabled the teachers to differentiate instruction and monitor students' engagement and understanding. In 2004-05 the students who used the Navigator System achieved at a level that was three times higher than the students in the control group. For the classes using the new technology, instructional decisions were based on the instant feedback of student understanding, and students' engagement was no longer considered a problem.

Another study, conducted on college students in an accounting course, had the goal of analyzing the effects of implementing additional instructional technology,

Blackboard Vista activities, on students' motivation and engagement (Mo, 2011). The participants in Mo's study were students who took the same course from the same professor in two different semesters in 2009. In both semesters the students utilized the Blackboard online platform to access course materials and email. In the second of the two semesters, the instructor added 12 optional online self-assessment quizzes, which could be taken multiple times, provided immediate access to correct answers, and did not impact student grades. In the spring 2009 semester, prior to the implementation of the self-assessment quizzes, 31 students serve as the control group. In the fall 2009 semester, when the new self-assessment quizzes feature was added, 44 students made up the test group. The statistical data tracking feature on Blackboard Vista was used to collect evidence about how student activities and course-related interactions changed when the optional online quizzes feature was added. Mo (2011) found that the test group participated in more online sessions, their sessions were longer, and they viewed more content and files than the control group; therefore, he concluded that an increase in available instructional technology features is associated with an increase in student engagement. Students in the test group also increased their number of email correspondences via Blackboard suggesting that the introduction of the online quizzes is related to improved course related interactions.

In a high school where most of the students receive free or reduced lunch and state tests in reading and writing are required for graduation, an English teacher sought to find a way to improve students' reading comprehension, vocabulary, and writing skills (Harmon, 2011). The teacher selected iPads to enable students to read iBooks[®] with

instant look-up for unfamiliar words. Then to differentiate instruction, the teacher selected a variety of apps for vocabulary acquisition and authoring stories. The teacher had a classroom set of 24 iPads that the students were not permitted to take home, but they used the iPads in class to write journal entries on the class web-page, take common assessments, collaborate on retelling works of drama, and compete with each other on vocabulary apps. To evaluate the effects of the program, the class with the iPads was the test group, and a class without iPads, but with the same curriculum, was the control group. Of all the students who took the State Department of Education reading and writing tests, 79% passed, while among the students who had used the iPads, 85% passed. The second measure used to compare the two groups was scores on the Measures of Academic Progress (MAP) tests which the students take three times per year. The reading and language usage MAP test scores from the end of the year were translated into grade levels. The iPad group averaged a beginning-of-eighth grade reading level and the control group averaged an end-of-sixth grade reading level. The iPad group averaged an end-of-ninth grade language usage level while the control group averaged a beginning-of-seventh grade language usage level. Students also completed pre and post Likert-scale surveys about their motivation and self-efficacy in reading and writing. The surveys revealed that the iPad group was more motivated to attend English class and they more accurately assessed their own reading abilities (perhaps as a result of experiencing accurate instant feedback about their reading skills). This author/teacher's research project resulted in "excitement for learning....No other pedagogical tool or technique

used in the author's career engages students in a way that made learning fun and left students feeling like they were in control of their own learning" (Harmon, 2011, p. 3).

In a Pennsylvania institution for students who have been abused or neglected, or who have emotional or behavioral problems, a teacher tried a technology solution to teach mathematics (Huffmyer, 2008). The teacher had Apangea Math and NetOP[®] installed in the schools' computer lab. He found that Apangea Math allowed him to tailor each student's learning path. The individualization motivated students and helped them build confidence. Implementing NetOP allowed him to simultaneously monitor what every student was viewing, take over any student's computer to provide help, and not have to leave his central position in the room. This way his help to each student remained confidential and he was able to maintain classroom management. This teacher reported that Apangea Math's motivation system engaged his students and made them want to work.

These studies and others measured the abstract construct of student engagement in a variety of ways (Harmon, 2011; Huffmyer, 2008; Kuh, Kinzie, Cruce, Shoup, & Gonyea, 2006; McClure, 2006; Mo, 2011; Shernoff, et al., 2003), and the focus of the instruments used to measure engagement revealed researchers' beliefs about what student attitudes, knowledge, or behaviors accurately reflect student engagement. Surveys were commonly used as data collection instruments to measure students' attitudes (Harmon, 2011; Kuh, et al., 2006; McClure, 2006; Shernoff, et al., 2003). Occasionally student achievement data was used as evidence of student engagement (Harmon, 2011; McClure, 2006). Another indicator that was sometimes used as a measure of student engagement

was the amount of time that student spent with the online program (Mo, 2011). Overall, evidence of student engagement was revealed in three different ways: student attitudes revealed through surveys, student knowledge measured through assessments, and student behavior recorded as time spent with online learning tasks. The current study made use of surveys, teachers' and observations' ratings, questionnaires, and achievement growth in an effort to gauge student engagement.

Flow Theory

Flow Theory has been applied to many different fields and it is helpful in explaining students' motivation when using computer technologies (Liao, 2006). In an effort to understand motivation, Csikszentmihalyi proposed Flow Theory in 1975; he described flow as a state of deep concentration; for example, when artists, musicians, or athletes become intensely involved in painting or performing, they are enjoying the process of what they do (Liao, 2006; Scherer, 2002). Csikszentmihalyi explained that "flow is the spontaneous, effortless experience you achieve when you have a close match between a high level of challenge and the skills you need to meet the challenge" (Scherer, 2002, p. 14). Flow is multidimensional, including a balance of skills to challenge, interactivity, clear goals, unambiguous feedback, concentration, a sense of control, a loss of self-consciousness, exploratory behavior, and a feeling of intrinsic motivation (Liao, 2006). These constructs align with the pedagogies that are afforded by ITS programs, particularly interactivity, clear goals, immediate feedback, a sense of control, and closely matched challenges and skills (Fleisher, 2006; Huffmyer, 2008; D. L. Johnson, 2005).

Critical variables contributing to flow are skill and challenge (Liao, 2006; Scherer, 2002);

Liao explained the importance of providing challenges that closely match skills:

People experience anxiety when their perceived challenges are greater than their skills; they feel bored when their perceived skills are greater than the challenges they face; and they are apathetic when both perceived skills and challenges are low. In contrast, people experience flow when their perceived skills and challenges are both high (Liao, 2006, p. 47).

Flow theory says when there is a balance between challenging tasks and the skills required to meet those challenges, flow or student engagement can occur. The result of flow is an experience that combines concentration, interest, and enjoyment simultaneously (Shernoff, et al., 2003). After a student has experienced flow, they will “intend to continue engaging in an activity and will want to explore new functions/features of the activity, ignoring the sense of time” (Liao, 2006, p. 54); thus, the state of flow is an intrinsic motivator.

Student engagement has been said to involve both challenge to and support for the learner (Balfanz, et al., 2007; Kuh, et al., 2006; Scherer, 2002). Students need challenge to give them direction, focus, and perseverance, and they need support to pacify their worries and fears (Scherer, 2002). To support flow and promote student engagement in learning, educational activities should be appropriately challenging, have clear goals, and provide feedback (Scherer, 2002). Because computer-assisted instruction (CAI) programs typically present challenges, have clear goals, and support student progress with hints and feedback, it is understandable that students tend to rate lessons that use

computers as highly engaging (Scherer, 2002). Furthermore, ITS programs are specialized CAI programs that use artificial intelligence, enabling the adaptation of lessons to better individualize instruction ensuring that the challenge of the tasks closely matches the students' skill levels and students have the opportunity to experience success (Fleisher, 2006; Huffmyer, 2008; D. L. Johnson, 2005). Therefore, based on Flow Theory, using an ITS program is expected to improve learning flow; thus, increasing student engagement and improving achievement.

The Evolution of ITS Programs

CAI programs, which were developed prior to ITS programs, rely on predetermined branching sequences to direct students through computer-based tutorials (D. L. Johnson, 2005). ITS programs differ from CAI programs in that ITS programs use artificial intelligence and cognitive psychology models to evaluate student knowledge and skills, provide feedback, and determine appropriate next exercises for the student (D. L. Johnson, 2005). Early research on ITS programs resulted in the development of a core tutor for basic algebra that provided flexibility for the creation of further versions differing in skills levels and pedagogies (McArthur & Stasz, 1990). The goal of creating different versions was to test them to determine which was most educationally effective. The levels varied from low-level procedural skills to high-level reasoning skills. The pedagogical policies varied from passive (students had to request help before the tutor would provide feedback), to intrusive (the tutor intervened to correct mistakes and give directions), to mixed (students could ask for help or tutor would intervene). McArthur and Stasz's (1990) preliminary report on a version featuring high-level skills and a

passive pedagogy revealed that it did not provide sufficiently clear feedback and it was too passive. This led to versions that were more intrusive and included more detailed hints and explanations.

There is evidence that a human tutor can increase student achievement by approximately two sigma or standard deviations (Bloom, 1984). Therefore, this became a goal by which to compare the effects of ITS programs, and designers proceeded to create versions of ITS programs modeled after human tutors.

The goal of intelligent tutoring systems (ITSs) would be to engage the students in sustained reasoning activity and to interact with the student based on a deep understanding of the students behavior. If such systems realize even half the impact of human tutors, the payoff for society promised to be substantial. (Corbett, Koedinger, & Anderson, 1997, p. 2)

Studies have been conducted to compare the effectiveness of ITS programs to traditional instruction, compare ITS programs to traditional CAI programs, and to compare different ITS programs to one another.

An ITS called PAT (practical algebra tutor), which was used in conjunction with PUMP (Pittsburg Urban Mathematics Project), was examined in a large scale study (Corbett, et al., 1997; Koedinger, Anderson, Hadley, & Mark, 1997) to determine how it affected student achievement. PAT focused on real world problems and representing them in tables, graphs, and symbolic notation; and it was used by the treatment group for 25 days out of a 180-day school year. PAT was based on a cognitive model, which is a system of if-then rules that track possible correct and incorrect solution steps. The

cognitive model supported model tracing (a process that compared each student's solution steps to possible steps derived by the model) and provided individualized hints or feedback to the student based on his or her steps. Scores on standardized tests and representations tests (created by the researcher) were significantly higher for students who used the PAT program than for the control group students who received traditional instruction alone. Furthermore, on the representations tests, the PAT students' scores were 1.2 sigma higher than control student's scores (Koedinger, et al., 1997), indicating that using PAT could result in gains that exceeded half of the gains expected with the use of human tutors.

An experimental pre-test/post-test study was conducted over a period of eight days (one hour per day) to measure the effects of providing CAI followed by an ITS compared to providing CAI alone on students' knowledge of algebraic expressions (Chien, Md.Yunus, Ali, & Baker, 2008). Results showed that the students who learned with CAI + ITS learned significantly more than those who learned with CAI alone. Chien, et al. (2008) concluded that this outcome was attributable to the useful personalized feedback and explanations that students received from the ITS.

Since ITS programs have evolved, the internet has improved delivery, and costs have come down allowing multiple developers to make ITS programs readily available (Barrus, Sabo, Joseph, & Atkinson, 2011), Barrus, et al. conducted a study to compare two off-the-shelf ITS programs, Carnegie Learning's Cognitive Tutor and ALEKS. The study took place during a 14-day (four hours per day) summer school class that 30 high school students who had failed algebra were taking for credit. Achievement for this

study was measured by algebra and arithmetic reasoning tests administered on Day 1, Day 7, and Day 13. A mixed ANOVA with the between-subjects factor of ITS program (Carnegie Learning or ALEKS) and the within-subjects factor of time (Day 1, Day 7, and Day 13) revealed a significant effect of time on scores, but there was no significant interactive effect between time and instructional program on scores. Students' scores improved significantly from each test administration to the next, but those gains did not differ significantly based on which ITS program had been used. This study showed that both ITS programs effectively remediated high school students in the context of a summer school program.

These studies demonstrated that ITS programs had positive effects on student achievement in a variety of settings and over varying lengths of time. They also provided evidence that ITS programs were more effective than traditional CAI programs; however, the outcomes from different ITS programs did not differ significantly. In the current study, the effectiveness of integrating an ITS program, Apangea Math, with face-to-face instruction for one semester was compared to face-to-face instruction alone for typical ninth grade, urban, high school students learning Algebra 1.

The Rise of Blended Learning

Online learning entered K-12 education to serve students who had no other options for learning, and typically occurred in situations involving advanced courses that were otherwise unavailable, remediation or recovery credits, or home-school and homebound contexts (Horn & Staker, 2011). Online courses provided students with equal access to quality courses no matter where they lived (Mupinga, 2005).

Furthermore, shrinking budgets, teacher shortages, and increased pressure for results brought online learning into school classrooms (Horn & Staker, 2011; Mupinga, 2005; Patrick, 2011). As online learning was integrated with face-to-face classroom instruction, it became known as blended learning. Horn and Staker (2011) define blended learning as “any time a student learns at least in part at a supervised brick-and-mortar location away from home and at least in part through online delivery with some element of student control over time, place, path, and/or pace” (p. 3). There was an advantage to blended learning: the integration of face-to-face instruction with online components of instruction maintained more contact between students and teachers than was possible in courses that were exclusively online, and this was seen as a way to prevent the high drop-out rates that were prevalent in online courses (Mupinga, 2005). Blended learning has changed the status of online learning in the K-12 environment; it was often considered just an add-on, but it is becoming an integral element of instruction (Horn & Staker, 2011; Patrick, 2011). The number of K-12 students who took online courses grew from 45,000 in the year 2000 to more than 3 million in 2009 (Horn & Staker, 2011). Proponents of technology see the blending of online learning and face-to-face instruction as a unique opportunity to restructure the educational system (Horn & Staker, 2011).

Blended learning in K-12 education takes different forms depending on the role of the teacher, scheduling, physical location, and method of delivery (Horn & Staker, 2011; Patrick, 2011). Horn and Staker identified six different models of blended learning with varying degrees of emphasis on the face-to-face portion and the online portion. The *Face-to-Face Driver* was a model where most of the content was delivered by the teacher in

the typical face-to-face format and online learning was reserved for supplemental instruction or remediation. The *Rotation* model featured a fixed schedule that divided instructional time such that students spend part of the time engaged in online, personalized instruction and part of the time with typical face-to-face instruction. For example, students who took a typical blended program including the ITS, Cognitive Tutor, spent 40% of their time online and 60% of their time in face-to-face classes (Viadero, 2007). In the rotation model, the same teacher usually provided the face-to-face instruction and moderated the online learning. The blended learning model practiced in the current study was a rotation model where students routinely rotated between face-to-face instruction and the Apangea Math online tutorial as a regular part of class time.

The remaining models described by Horn and Staker (2011) all contained higher percentages of time spent online. The *Flex* model featured an online program that delivered most of the content, and the teacher provided support in the form of individual or small group tutoring. The *Online Lab* model featured an online platform that delivered the entire course to students who had access to online teachers and were monitored by paraprofessionals in a school computer lab. The *Self-Blend* model involved high school students taking an online course remotely to supplement the courses they took at school. The *Online Driver* was a model where students accessed all of their curricula remotely via an online platform and online teachers, while face-to-face interactions were reserved for occasional check-ins and possibly extracurricular activities.

Impact on students. When the online environment is personalized, self-paced, and interactive, the student's role becomes an active, self-motivated, and self-directed worker (Butler, 2010; Mupinga, 2005; Reigeluth, 2011). This provides students with the opportunity to take greater responsibility for their education (Mortensen, 2011; Snoeyink & Ertmer, 2001).

An important skill that helps students become effective learners is self-regulation, which they develop as they learn when seeking help is appropriate while they are using an ITS program (Aleven, Roll, McLaren, & Koedinger, 2010). There are two undesirable help-seeking behaviors that are seen when students use ITS programs: help-avoidance and help abuse. With help avoidance students fail to access hints when needed, and with help abuse students click through all the hints to find an answer without thinking (Aleven, et al., 2010; Roll, et al., 2011). In Roll et al.'s (2011) study, adding a Help Tutor onto the Cognitive Tutor trained students to think about their help-seeking decisions. This study demonstrated the need for teachers to coach students, suggesting that students stop and think about what they know before accessing hints and encouraging students to access hints when they need help.

Impact on teachers. The most important factor of implementing an innovative learning program is the teachers who deliver the intervention (Protheroe, 2008). Curriculum interventions must be implemented with fidelity, which refers to integrity and adherence to delivering content in the manner in which it was intended (E. Johnson, et al., 2006; O'Donnell, 2008; Protheroe, 2008). This is critical because if an intervention program is delivered in a way that is quite different from the way it was designed, than

the lack of fidelity may limit the expected outcomes (Lendrum & Humphrey, 2012; O'Donnell, 2008; Protheroe, 2008). A factor that tends to contribute to reduced levels of implementation fidelity is teachers' beliefs that the approach of the intervention will not be effective or it does not fit their teaching style (Protheroe, 2008). In this study, teachers implemented a technology based intervention, Apangea Math, making it necessary for teachers to integrate what they knew about technology with their content knowledge and their understanding of pedagogy.

Shulman (1986) introduced the need for teachers to integrate subject content knowledge and pedagogy as pedagogical content knowledge (PCK) in order to successfully represent information in a way that students can learn. Twenty years later, Mishra and Koehler (2006) expanded on this theory by recognizing the growing importance of technology in education, explaining that “merely knowing how to use technology is not the same as knowing how to teach with it” (p. 1033). Mishra and Koehler developed the theoretical framework they called Technological Pedagogical Content Knowledge (TPACK) to describe what teachers need to know in order to effectively teach with technology. The knowledge of content, pedagogy, and technology should not be viewed separately, but as overlapping and interrelated resulting in seven domains of knowledge: technology knowledge, content knowledge, pedagogical knowledge, pedagogical content knowledge, technological content knowledge, technological pedagogical knowledge, and technological pedagogical content knowledge (Mishra & Koehler, 2006; Mishra, et al., 2009; Schmidt, et al., 2009b). See Figure 1.

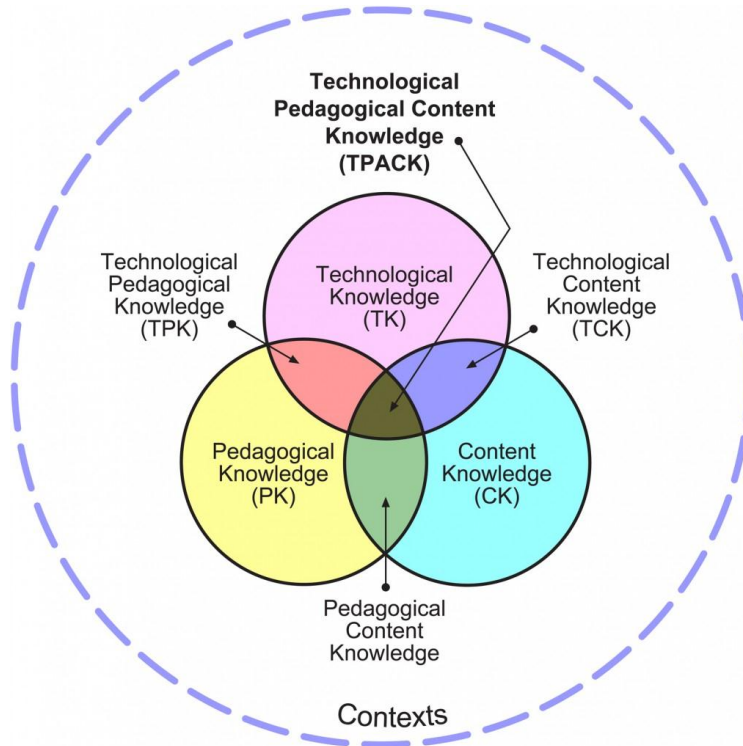


Figure 1. The components of the TPACK framework (graphic from <http://tpack.org>).

The TPACK framework supports thinking about what teachers should know to integrate technology into lessons. Subsequently, to measure pre-service elementary teachers' knowledge development in each of the seven domains of TPACK, Schmidt, et al. (2009b) developed a TPACK survey instrument.

In addition to what teachers need to know to teach with technology, researchers have explored how teachers come to develop this knowledge and integrate technology into their teaching. Niess et al. (2009) explained that teachers go through a five-stage process when learning to integrate technology that is new to them into their teaching of mathematics. The Mathematics Teacher TPACK Development Model (Niess, et al., 2009) describes the five stages beginning with technology knowledge (TK) separate from

PCK. At the first stage, *recognizing*, teachers know that technology is available but have not yet used it in their teaching. During the second stage, *accepting*, teachers begin to be persuaded by the notion that using the technology may be appropriate for teaching and learning. In the third stage, *adapting*, teachers make the decision to interact with the technology in preparation for its possible use in teaching. In the fourth stage, *exploring*, teachers actually integrate the technology into the teaching and learning of mathematics. The final stage, *advancing*, is the point when teachers evaluate the results of using the technology and integrate their TK with their PCK resulting in TPACK knowledge.

Integrating instructional technology not only alters what teachers need to know, it also changes the role that teachers play. The typical role that teachers are accustomed to playing in face-to-face instruction is that of an expert, authority, or model; however, their new role when online instruction is employed is that of a guide, delegator, or facilitator (Butler, 2010; Comas-Quinn, 2011; Patrick, 2011; Reigeluth, 2011; Snoeyink & Ertmer, 2001; Zhu, 2010). In a blended model, the teachers' role goes through a transformation, data begins to drive instructional decisions, and the teacher's role becomes "learning coach, catalyst, and facilitator" (Patrick, 2011, p. 22). Research by Comas-Quinn (2011) revealed that when teachers are trained for the adoption of new technology, knowledge about the technology and how to use the technology are emphasized, while understanding what makes the technology effective and how the role of the teacher changes tends to be neglected. It is important for teachers to be aware of the pedagogical affordances provided by instructional technology (Butler, 2010; Snoeyink & Ertmer, 2001), and for both teachers and students to understand how to use the new technology and why the new

technology is expected to improve learning (Comas-Quinn, 2011). Furthermore, new models of instruction have the potential to change teachers' workloads based on how many students each teacher can manage in online or blended environments compared to face-to-face arrangements (Mupinga, 2005). "How teachers accept and adjust to these changes will no doubt influence how students learn" (Snoeyink & Ertmer, 2001, p. 86).

Challenges expected. Changes that are part of implementing online or blended learning educational programs can be described as either first-order or second-order; first-order challenges are extrinsic in nature, while second-order challenges are intrinsic. (Ertmer, 2005; Snoeyink & Ertmer, 2001; Wachira & Keengwe, 2011). First-order challenges are readily visible and measurable as they involve changes in practice that take place over time without altering existing beliefs (Ertmer, 2005). Second-order challenges are more difficult to see, measure, and change (Wachira & Keengwe, 2011). First-order changes tend to precede second-order changes, and first-order challenges also tend to conceal second-order challenges (Snoeyink & Ertmer, 2001).

First-order challenges can be financial constraints, limited access to computers, lack of interactive software, malfunctioning computers, slow network servers, unavailability of technical support, or inadequate technology leadership (Snoeyink & Ertmer, 2001; Wachira & Keengwe, 2011). Some claim that a lack of access to computers and quality software are the primary barriers to integrating technology (Wachira & Keengwe, 2011), while others claim that access to technology is generally adequate (Ertmer, 2005). Some claim that the initial costs of training teachers to effectively use online resources and students to become self-directed is challenging with

tight budgets (Mupinga, 2005), but others claim that by the third year of implementation, an online or blended learning program can be self-sustaining (Devaney, 2012). Among technical issues, Devaney (2012) stated that to avoid network crashes, internet connectivity needs to be able to support many students accessing the network simultaneously. Ongoing and immediate technical support are basic demands of online and blended educational programs (Butler, 2010); however, some mathematics teachers have been discouraged about using technology based on a fear that it would fail in the middle of instruction and response times from technical support staff were consistently slow (Wachira & Keengwe, 2011). Communication with everyone involved in implementing new technology is important (Devaney, 2012), yet “teachers including the math coaches reported that they were hardly involved in decision making as to what technology was needed in their schools” (Wachira & Keengwe, 2011, p. 20).

Second order challenges involve the organizational culture of schools and teachers’ knowledge, attitudes, and fundamental beliefs about pedagogy (Snoeyink & Ertmer, 2001; Wachira & Keengwe, 2011). Teachers’ beliefs about pedagogy are heavily influenced by their image of what is familiar, possible, and appropriate for classroom practices; therefore, their beliefs about the appropriate use of technology in education is slow to change (Ertmer, 2005). One school culture factor that teachers reported as limiting their ability to experiment and learn about new technology was a lack of time caused by increasing demands to prepare students for state tests (Wachira & Keengwe, 2011). Wachira and Keengwe’s research also showed that teachers find it difficult to manage their students in computer labs where many students would likely be off-task.

Studies revealed that some teachers lacked the skills to use the available technology, while others who knew how to use the technology did not have the pedagogical knowledge to use the technology in content-specific ways to enhance learning (Snoeyink & Ertmer, 2001; Wachira & Keengwe, 2011). Snoeyink and Ertmer (2001) predicted, “Once teachers perceive that using computers improves learning, the barriers will come down” (p. 88).

Change is difficult and can be hard for people to accept (Butler, 2010; Devaney, 2012). Teachers may be concerned that a change toward online or blended learning may be a move towards reducing staff (Butler, 2010). As mentioned earlier, clear communication and discussion about the pedagogical affordances of technology can help everyone understand and accept why some of the changes are happening.

Summary of Literature Review

Computing in K-12 education has evolved rapidly over the past three decades. Beginning in the 1980’s, when the ratio of students to computers was many to one, students learned *about* technology; in the 1990’s, as the ratio became one student to one computer, students learned *from* technology; now that the ratio is one student to many devices; students learn *with* technology (Chen, et al., 2011). In the last decade, computing has become ubiquitous, meaning internet connections and mobile devices make it possible for students to access learning content from anywhere, anytime.

Technology has a role to play in meeting the needs of the post-industrial age educational system. The current knowledge-based economy demands that all students learn Algebra 1, the gatekeeper to higher-level mathematics. Implementing the use of

instructional technology to teach mathematics must be done in pedagogically appropriate ways because technology use alone does not necessarily lead to improved student outcomes. Existing studies revealed that when instructional technology provides opportunities that include interactivity, immediate feedback, and a close match between the challenge of learning activities and students' skills, student engagement improves and achievement increases. Studies pointed to evidence of student engagement based on students attitudes toward learning, student achievement scores, and the amount of time students spent engaged in learning tasks. The pedagogical features that were afforded by technology in cited studies closely aligned with factors that contributed to learning flow; thus, a case was made offering Flow Theory as an explanation for why thoughtfully implemented instructional technology improves student engagement.

Blended learning which combines face-to-face instruction with online learning is growing in popularity in the K-12 educational environment. There are multiple models of blended learning that vary in how much emphasis is place on each mode of learning: face-to-face instruction and online learning. ITS programs tend to adopt the rotation model of blended learning where the classroom time is set up on a fixed scheduled for students to rotate between the two modes of instruction. To facilitate learning in a blended learning environment, teachers need to understand how knowledge of content, pedagogy, and technology are interrelated. Teachers' role becomes coach or facilitator as students access content from an online program, and they use student progress data to make decisions about differentiating instruction. Students, interacting with the online

program, become more self-directed, take responsibility for their own learning, experience incremental success, and progress at their own pace.

Many challenges are expected when schools implement new technologies in instruction. In many schools, first order (external) challenges have been met while second order (internal) challenges continue to pose barriers to effective technology implementation (Ertmer, 2005). Exactly what shape computing in K-12 education will take in the future remains to be seen. It has been suggested that educational technology may be approaching a 'Columbus Effect' meaning innovations may lead to benefits or challenges that no one has even begun to anticipate (Fletcher, 2011).

Chapter 3

Methodology

The methodological choices I made in designing this study are based on my personal metaphysical assumptions. The data collected is primarily quantitative, particularly in regards to student achievement, student engagement, and fidelity of implementation. However, qualitative data was also collected about challenges teachers encountered and teaching practices used. The design is quasi-experimental and considerations regarding internal validity were addressed.

Methodological Theoretical Framework

My personal metaphysical assumptions support positivist methodologies. My ontological and epistemological views support the notion that there is truth to be discovered, and it is the responsibility of researchers to search out, study, and disseminate truth to the best of their abilities. I believe researchers should be as objective as humanly possible in order to isolate and analyze meaningful empirical data in their studies of particular phenomena. I think learning about and knowing important truths relies on the construction of theories and frameworks to observe, categorize, and measure phenomena. I believe a well-designed survey instrument based on sound substantive theories can be used to examine and analyze somewhat abstract constructs such as student engagement.

Studies involving many participants for a length of time are well-suited to quantitative analyses. Quantitative analyses reveal the magnitude of the effects of interventions. However, researchers interested in causal relationships recognize that analyzing outcomes is of limited consequence if the implementation process of the

intervention is not documented (Fleischman & Williams, 1996; Lendrum & Humphrey, 2012; Trochim, 1986). Thus, the framework for evaluating an instructional program combines an outcome evaluation with a process evaluation (Fleischman & Williams, 1996). The outcome component indicates the extent to which objectives are reached, and the process component describes the program implementation in an attempt to reveal what contributed to the success or failure in meeting those objectives. Therefore, in this study, the plan was to primarily use quantitative data to describe and analyze the implementation process, student engagement, and achievement. Then these analyses were supplemented by qualitative descriptions regarding the challenges teachers encountered and the practices they used when implementing the program.

Internal Validity

This study lasted one semester, spring 2012, and took place in a natural school setting in an urban high school. Doing research in classroom settings, with all their complexity, makes isolating the effects of the intervention from other possible influences very challenging (A. L. Brown, 1992). Thus, it was essential to make an effort to design the study so that alternate explanations for possible changes were minimized in order to establish internal validity.

When the goal of research is to assess the effects of interventions, as it is with this study, issues of internal validity are highly important. According to Trochim (2006), “internal validity is the approximate truth about inferences regarding cause-effect or causal relationships” (Internal Validity section, para. 1). True experimental design using randomized assignment of participants is the gold standard for establishing internal

validity because they are the “strongest tools available with which to infer cause” (Berk & Rossi, 1999, p. 21). However, this study involved students that were organized into intact classroom groups. Because this arrangement was not randomized, it was not considered a true experimental design; it was a *quasi-experimental* design, which had the features of experimental design, but lacks the random assignment (Trochim, 1986).

Since the design of the study was quasi-experimental, caution was emphasized when attempting to infer causation. In order to establish a causal relationship, a study must show that (a) the cause happened before the effect; (b) there is a relationship between the program and the observed outcome; thus, a change in the dosage of the program would result in a change in the observed effect; and (c) no other alternative explanation could account for the changes that came about during the implementation of the intervention (Trochim & Land, 1982). When considering causal relationships in this study of the effects of the Apangea Math program, (a) the instructional program clearly preceded the measures of final outcomes and (b) it is widely accepted that receiving instruction is related to academic growth, but (c) it was difficult to rule out the possible existence of alternate explanations for the changes that participants experienced.

This study had two groups: an intervention group of students who had access to Apangea Math and a comparison group made up of previous classes of similar students who did not have access to Apangea Math. The key to successful two-group designs is having the two groups be comparable to a very high degree based on pre-intervention characteristics. The best way to ensure that groups are comparable is via random assignment; but, when the design is quasi-experimental, as it was in this study, the groups

are not necessarily comparable so they are referred to as non-equivalent groups. Threats to internal validity for non-equivalent groups can be caused by *selection bias*, which occurs when the groups are not comparable prior to the treatment or by *social interaction threats*, which are social pressures experienced by the participants or the people who are carrying out the study, which result in posttest differences that were not caused by the treatment. Potential threats to internal validity can be logically minimized if the intervention and the comparison groups are comparable (Trochim & Land, 1982). The possibility that the two groups may consist of students with substantially different abilities, prior knowledge, or other characteristics presents the potential for different outcomes because “instructional treatments may either facilitate or inhibit learning depending upon effects of their structural characteristics on different types of learners” (Jonassen & Grabowski, 1993, p. 10).

Social interaction threats can be caused by imitation of treatment, compensatory rivalry, resentful demoralization, or compensatory equalization. Each of these conditions occurs when the control group students or their teachers change their behaviors as a reaction to knowing about the test group. None of these threats were possible in this study because the school administrators determined that all of the students who were taking Algebra 1 in spring of 2012 would participate in the Apangea Math program. This decision was made primarily because there was concern that if some students were provided the innovative blended-learning intervention as a test group while other students were denied access to the online tutorial via the wireless tablet computers as a control group then the potential for resentful demoralization would be too great. Resentful

demoralization is an undesirable phenomenon that occurs when a control group decides to give-up because they are angry about not getting the same treatment as the test group. Therefore, it was determined that previous classes of similar Algebra students would serve as the comparison group for this study. In this way, possible social interaction threats were avoided, and the school maximized the usage of the Apangea Math program.

Selection bias can cause threats to validity based on selection-history, selection-maturation, selection-testing, selection-instrumentation, selection-mortality, or selection-regression. The selection bias that posed the greatest threat to this study was selection-history threat which refers to experiential differences that happen between the pre-test and the posttest (besides the treatment) that would cause the groups to differ. In this study, the intervention group and the comparison group data were generated in different semesters; thus, if the two groups were exposed to substantially different conditions other than their instructional treatment, those differences would have to be considered possible predictors of the subsequent outcomes.

In consideration of selection-history threat, it was essential to consider the similarities and possible differences between the two treatment groups. The intervention group and the control group both consisted of ninth grade students from the same high-school who were of similar ethnic and socioeconomic backgrounds. Both groups were being taught the same curriculum for Algebra 1 based on TN state standards. Both groups took the same student achievement tests: Discovery Assessments and the Algebra 1 EOC. Half of the intervention group teachers taught the control group the previous year; however, the other teachers were not the same for both treatment groups. Teachers,

in general, can be expected to naturally and regularly differentiate instruction to meet the needs of their students; but since teachers vary in the amount of small group or individualized instruction that they provide, it must be acknowledged that this alone could have caused changes in student engagement and achievement. Therefore, to minimize the possible selection-history threat posed by the different teachers, the outcomes of both the intervention group and the comparison group were derived from many classes taught by multiple teachers, thus reducing the influence of each individual teacher.

Procedures

The plan for the blended instruction curriculum included classroom time dedicated to using Apangea Math in addition to time for face-to-face instruction. In December, 2011, a representative from Apangea came to the school and conducted a training session, introducing the teachers to the online tutorial program. I also met with the Algebra 1 teachers in December to discuss and establish expectations for scheduling class time for the use of Apangea Math and including students' Apangea Math progress in their course grades. At that meeting, the expectation for Apangea Math usage was set at 40 minutes of each 90-minute class for 4 days per week. This provided teachers a flexible structure for lesson planning; out of the 450 minutes of weekly class time, teachers could determine exactly when to provide the students with approximately 160 minutes of time to work on Apangea Math. This delivery method fit the rotation model of blended learning since teachers would schedule students to rotate between the two modes of instruction, and the students' face-to-face teacher would monitor their online

work as well (Horn & Staker, 2011). Teachers expected students to pass four Apangea Math lessons per week, and it was planned that students would receive weekly Apangea Math grades that would ultimately count as 25% of their overall course grades.

In early January, 2012, the high school's instructional technology coordinator conducted training on the use of the wireless notebook computers and how to maximize connectivity to the network. The wireless tablet computers that were dedicated exclusively to this Algebra 1 initiative were set up so that student's internet access was restricted to just one website, Apangea.com. This was done as a proactive measure to ensure that students would not be distracted by access to other internet sites.

The students in the intervention group were each provided a wireless tablet computer to use during math class to access Apangea Math. They were not permitted to take the tablets home due to security concerns for the students and the equipment, but they were provided with the ability to access their Apangea accounts at any time from any computer with internet access, so that access outside school was possible. Their outcomes were compared to that of the previous spring's classes of Algebra 1 students, who were taught with face-to-face classroom instruction without access to Apangea Math. The intervention group and the comparison group were similar in their demographic and socioeconomic characteristics, and the curriculum standards and standardized tests had been the same for three school years. Thus, the main variable that differed between the two groups was the instructional treatment: the intervention group had access to Apangea Math but the comparison group did not.

When students initially accessed their Apangea accounts, they were prompted to take a diagnostic placement test which determined an appropriate level for each student to begin the online tutorial lessons. This insured that challenges presented in subsequent Apangea lessons would closely match each student's skills. When students had difficulty with the content in a lesson, computerized hints provided assistance, and as students continued working, they could move between screens to review explanations. If students continued to have difficulties, a live Apangea Math tutor would assist them. The students communicated with the tutors via an online chat box and the tutors responded via chat, whiteboard, or verbally through an audio connection. In this manner, students received immediate, unambiguous feedback.

All of the teachers in the high school where this study took place attended PD sessions afterschool every Wednesday. For the four ninth grade Algebra 1 teachers, about three of these sessions per month were dedicated to meeting with me to collaborate about the implementation of the blended learning program. During these meetings, I conducted the PD, which focused on reviewing protocols that were recommended by Apangea Learning as best-practices for implementation. I also facilitated discussions among the teachers about the challenges they encountered and the practices they employed while enacting blended learning. Furthermore, I collected the teachers' weekly Implementation and Observation Forms, and I used data that was generated by Apangea Math's online statistics regarding students' usage and lessons passed to analyze student progress.

There were three modes by which the level of adaptability of Apangea Math could be controlled: fully adaptive, learning pathways that were adaptive, or learning pathways that were not adaptive. When the program was in its fully adaptive mode, which was the mode recommended by the Apangea representative, the lessons presented to each student depended on the results of the student's placement test as well as his or her continuous progress on lessons. For example, if a student's placement test results indicated he or she had mastered mathematics to the level of sixth grade, he or she was presented seventh and eighth grade mathematics content prior to Algebra 1 content. The creators of Apangea Math included an option for creating what they termed "learning pathways," an option that allows administrators or teachers more control over the content presented in the online tutorial. When creating learning pathways, there was an option to flag them as adaptive or not adaptive. If a learning pathway was not designated as adaptive, only selected lessons would be presented to the students who were assigned to that pathway. If a learning pathway was designated as adaptive, precursor lessons necessary for success in the selected lessons were presented to students who had not previously demonstrated mastery in the precursor concepts. In the current study, students worked in the fully adaptive mode for about two-thirds of the semester. Challenges that emerged led to the creation of learning pathways that were adaptive, and students interacted in that mode for the remainder of the semester. The third mode, learning pathways that were not adaptive, was never used at all.

Participants

The intervention group consisted of 75 ninth grade Algebra 1 students, 40 male and 35 female, who took Algebra 1 in the spring of 2012 at one urban high school. The ethnic make-up of the group was 85.3% Black, 12.0% White, 1.3% Hispanic, and 1.3% Asian/Pacific Islander. Socioeconomic statistics described 90.7% of the students as economically disadvantaged.

The comparison group consisted of 99 ninth grade Algebra 1 students who took Algebra 1 at the same urban high school during the previous spring semester, 2011. The demographic make-up of the student population of the high school during that school year was 88.6 % Black, 10.0 % White, 0.8 % Hispanic, 0.4 % Native American/Alaskan, and 0.1 % Asian/Pacific Islander, with 86.6 % of the students being economically disadvantaged. These statistics confirm that the demographic characteristics of the intervention group were similar to those of the comparison group.

At this high school, Algebra 1 is typically taught to ninth grade students in one of two ways: either as a one-semester class or a year-long class. Students who arrive to high school prepared to take Algebra 1 enroll in a one-semester Algebra 1 class. Those who are not prepared to take the one-semester class enroll in a year-long class which is broken into Algebra 1A and 1B. Students receive elective credit for one semester of Algebra 1A and math credit for one semester of Algebra 1B. The intervention group students were arranged into eight intact classes with seven of those classes enrolled in Algebra 1B taught by four teachers, and the remaining class enrolled in semester-long Algebra 1 taught by one of the four teachers. The comparison group students were arranged into

nine intact classes with eight of them being Algebra 1B taught by five teachers and one of them being semester-long Algebra 1 taught by one of the five teachers. The average class sizes for the intervention group and the comparison group were 9.4 and 11 students respectively. All the intervention group and comparison group students enrolled in Algebra 1B or Algebra 1 were required to take the state EOC exam for Algebra 1 at the conclusion of their courses (TN Department of Education, 2010).

There were four ninth grade Algebra 1 teachers during the intervention period in spring of 2012, and they were active participants in the study. Their ethnic composition was one Black and three White, and their genders were two male and two female. One of them had between 10 and 15 years prior teaching experience while the other three had less than five years. Two of the intervention group teachers had bachelor's degrees (one in sociology and one in accounting and finance), and two had master's degrees (one had a bachelor's in psychology and a master's in math education, and the other had a bachelor's in engineering and a master's in education).

Five teachers taught ninth grade Algebra 1 during the comparison semester in spring of 2011. Their ethnicities were two Black and three White, and their genders were two male and three female. Their years of prior teaching experience were as follows: one had between 15 and 20 years, one had between 10 and 15 years, one had between five and 10 years, and two had less than five years. Three of the comparison group teachers had bachelor's degrees (one in sociology, one in mathematics, and one in secondary math education), and two had master's degrees (one had a bachelor's in mathematics and a

master's in counseling, and the other had a bachelor's in engineering and a master's in education).

The teachers who taught the intervention and comparison groups were similar in educational background, teaching experience, and demographic characteristics. Note that two teachers taught both years, but the rest were different. All of the teachers that taught the intervention and comparison groups were certified as highly qualified. They all took the Praxis content knowledge test for secondary mathematics which examined their competencies in both content and process categories (Educational Testing Service, 2011). The content categories tested included algebra and number theory, measurement, geometry, trigonometry, functions, calculus, data analysis and statistics, probability, matrix algebra, and discrete mathematics. In addition to proving their knowledge of the mathematics content, this test required these teachers' to demonstrate their understanding of how concepts are learned and applied by successfully responding to questions in the processes categories of problem solving, reasoning and proof, mathematical connections, representations, and the use of technology.

Data Collection

There were two quantitative sources of student achievement data for both the intervention group and the comparison group. Discovery Assessment (DA) formative tests were administered twice during the spring semester as pre- and post-tests, and the Algebra 1 EOC exam was administered as a summative test.

Data regarding the intervention group students' attitudes towards learning mathematics and reactions toward the Apangea Math program was gathered from

multiple sources. Likert-scale student engagement surveys were administered twice, at the beginning and at the end of the intervention semester, to measure changes in students' attitudes towards learning mathematics. Implementation and Observation forms that were completed weekly by teachers and periodically during classroom observations provided ratings of participant responsiveness toward Apangea Math. Additionally, the school administered anonymous multiple choice questionnaires to the intervention group students and their teachers at the end of the semester to gauge reactions towards Apangea Math.

Data about the implementation of the program was derived from both quantitative and qualitative sources. Teachers completed a Likert-scale modified Technological, Pedagogical, and Content Knowledge (TPACK) survey, providing insight into their knowledge and attitudes towards educational technology. Online Apangea Math statistics provided quantitative details about the amount of time students spent using the program and the number of Apangea lessons they passed. On the weekly Implementation and Observation forms, teachers rated fidelity of implementation, estimated the percent of time they spent in different roles, and wrote about challenges they encountered and practices they found beneficial. Classroom observations spot checks were conducted to complete the same form that the teachers used in order to verify teachers' ratings and comments. Notes recorded during ongoing classroom visits and teachers' professional development and collaboration meetings further documented implementation processes, challenges that were encountered, and practices that were used.

Instruments

Algebra 1 EOC exam. The Algebra 1 EOC exam is the standardized high-stakes state test that was administered at the conclusion of the course. This is the third school year that this version of the Algebra 1 EOC exam has been in use so the intervention and comparison groups had comparable data.

Discovery assessments. DAs are computer-based tests that were administered to the Algebra 1 students in the intervention group in spring of 2012 and the comparison group in spring of 2011. These tests, which were administered in January and in April, measured mathematics achievement and were intended to provide teachers with benchmark data regarding students' readiness to take the high-stakes Algebra 1 EOC exam. This is the third school year that the high school has been using these tests, so the intervention group and the comparison group had data that is comparable. Each DA test consisted of 32 questions which were sub-scored based on five reporting categories (Discovery Education, 2012), which aligned with the content standards in the Tennessee Mathematics Standards 2009-10 Implementation of Algebra 1 (TN Department of Education, 2009). The State Performance Indicators (SPIs) of the TN Mathematics Standards corresponded with the DA reporting subcategories (see Appendix A). The DA test consisted of six questions from Standard 1, Mathematical Processes, including interpreting patterns, identifying slope in multiple contexts, understanding equations for contextual problems, using an equation in context, applying properties, and translating representations of functions. Four questions were from Standard 2, Number and Operations, which tested ordering real numbers, operating with radicals, and

computing numbers in scientific notation. Twelve questions involved Standard 3, Algebra; namely, generalizing a pattern, determining domain and range, interpreting relations, writing the equation of a line, understanding linear equations with two variables, representing linear equations and inequalities, analyzing a nonlinear graph, interpreting quadratic functions, simplifying rational expressions, operating with polynomials, and factoring polynomials. Four questions addressed Standard 4, Geometry and Measurement, such as determining the distance between points, estimating the area of a shape, using the Pythagorean Theorem, and converting rates and measures. Six items were about Standard 5, Data Analysis, Statistics and Probability, including understanding a scatter plot, understanding change in a data set, interpreting a display of data, applying the equation of a line, and determining probability. The level of difficulty varied from easy to hard throughout the assessment.

For the sake of clarification, some terms that sound similar but refer to different things need to be explained. The term “Mathematical Processes” in TN Mathematics Standards for Algebra 1 refers to a content standard, which is listed with its specific SPIs in Appendix A. This is different from the NCTM “Process Standards,” which are described in *Principles and standards for school mathematics* (National Council of Teachers of Mathematics, 2000) and refer to broad practices, including problem solving, reasoning and proof, communication, and representation and connection that apply to all content standards across all grade levels from prekindergarten to Grade 12. The Common Core State Standards have recently expanded the NCTM’s Process Standards, called them the “Standards for Mathematical Practice,” and described them as the

“varieties of expertise that mathematics educators at all levels should seek to develop in their students” (Common Core State Standards Initiative, 2010a). The CCSS Standards for Mathematical Practice, like the NCTM Process Standards apply broadly across all content standards and across all grades. Thus, the Algebra 1 content standard called Mathematical Processes, the NCTM Process Standards, and the CCSS Standards for Mathematical Practice each refer to different things.

Student engagement survey. Student engagement surveys were administered to generate self-reported student engagement scores for the intervention group students, once at the beginning of the intervention and again near the end of the semester. The survey instrument (see Appendix B) was adapted from one developed by Velayutham, Aldridge, and Fraser (2011) to measure students’ adaptive motivational beliefs and self-regulation in order to gauge their engagement in the learning process. The Likert-scale survey items could be responded to with a range of 1 (*strongly disagree*) to 5 (*strongly agree*). The authors developed the instrument identifying four constructs that contribute to student engagement: (a) learning goal orientation, (b) task value, (c) self-efficacy, and (d) self-regulation.

The following established substantive theories link these four constructs to student engagement. Achievement Goal Theory describes *performance goal orientation* as focusing on earning a grade or impressing others and *learning goal orientation* as focusing on learning for the sake of mastery (Velayutham, et al., 2011). Performance goal orientation can undermine students’ motivation and achievement (Urdan & Schoenfelder, 2006), but learning goal orientation is a component of adaptive

motivational orientation (Kaplan & Maehr, 2007). Therefore, learning goal orientation was included in the development of the survey instrument. Expectancy-Value Theory claims there is a positive relationship between the value students see in a task and their decision to participate and persevere in that task (Wigfield & Eccles, 2000); thus, task-value was included in the survey instrument. Self-Efficacy Theory suggests that students who believe they can perform will have greater incentive to expend effort to learn (Bandura, 1977); therefore, self-efficacy was the third construct measured with the survey. The fourth construct included in Velayutham et al.'s survey instrument was self-regulation, which involves a student's personal choice to engage in learning, effort invested to persevere, and adaptive skills (Zimmerman, 2008).

Velayutham et al.'s (2011) survey instrument was thoughtfully constructed and tested for reliability and validity. It was appropriate for collecting data from the ninth grade Algebra 1 students because it was designed to assess factors supporting student engagement among students in eighth to tenth grade. Even though it was originally designed to assess student engagement with science learning, Velayutham et al. recommended that the survey be modified to assess students' adaptive learning engagement in other disciplines. The only adaptation made to the survey for this study was the replacement of the word *science* with the word *math*.

The adapted 32-questions survey contained eight items for each of the following constructs: learning goal orientation, task value, self-efficacy, and self-regulation. Velayutham et al. evaluated their survey instrument for construct validity and succeeded at establishing strong validity in all six of the following areas:

- content validity which requires sound theoretical underpinnings;
- face validity which requires clarity, particularly when interpreted by participants;
- convergent validity which requires that the items within each construct be highly correlated to each another;
- discriminant validity which requires that items from different constructs not be highly correlated to each other;
- concurrent validity which requires that groups that should theoretically be different are distinguishable; and
- predictive validity which requires that each construct be able to predict what it theoretically should predict.

The internal consistency reliability for the survey was determined by calculating the Cronbach alpha for each construct. The Cronbach alpha coefficient for each was above 0.90; thus, the constructs were considered reliable.

Implementation and observation form. The Teachers' Implementation and Observation Form (see Appendix C) was the weekly form completed by the four teacher-participants. On this form, teachers rated the fidelity of the implementation of the Apangea Math program and estimated the percent of time that they spend in various roles. They also answered open-ended questions about challenges they encounter and teaching practices they found beneficial when enacting the blended curriculum. Fidelity was measured by rating four aspects of implementation (i.e., adherence, exposure, quality of delivery, and participant responsiveness) on a scale from 1 (*low*) to 5 (*high*).

Adherence referred to the extent which students complied with the activities that should take place when they were using the Apangea Math program; namely, accessing the program online, using headphones, using calculators, and working out problems on paper. Exposure was the dosage students received measured by the amount of class time they spent on the Apangea Math program. Quality of program delivery was a measure of the smoothness of delivery with 1 indicating many technical problems and 5 indicating smooth delivery with no technical difficulties. Data regarding additional factors that influenced quality of delivery; specifically, teachers' TPACK knowledge and attitudes, were collected by way of a survey and notes taken during observations and meetings. Participant responsiveness referred to the level of attention that students gave to their work with the program where 1 meant most of the students were not engaged nor working while 5 meant all the students were engaged and working. See Appendix C for additional details regarding the ratings of the fidelity of implementation.

The role that teachers played while enacting the blended curriculum was measured by their estimation of the percent of time that they spent weekly on different activities such as whole class instruction, one-on-one or small group instruction, monitoring group work, monitoring online work, trouble-shooting technical problems, discipline, and analyzing reports. In addition to the teachers' self-reported data, classroom observations were conducted two or three times in each of the eight classes as spot-checks when the same observation and implementation form that the teachers used was completed in order to provide supplemental data.

Student questionnaire. School personnel administered an anonymous multiple choice questionnaire to the intervention group students at the end of the semester to gather their reactions to the Apangea Math program (see Appendix D).

Teacher questionnaire. School personnel also administered an anonymous multiple choice questionnaire to the teachers of the intervention group to collect their feedback regarding the Apangea Math program (see Appendix E).

TPACK survey. As discussed in the participants section, all of the teachers were classified as highly qualified. However, because this study focused on the implementation and effectiveness of integrating a technology based intervention into the teaching and learning of mathematics, it was relevant to gather additional information about the intervention group teachers' TPACK knowledge. Teachers TPACK knowledge could affect the quality of program deliver which is one of the four constructs of fidelity of implementation (Mihalic, 2002). Teachers' TPACK knowledge was measured by their completion of a self-assessment TPACK survey. Schmidt, et al.'s (2009b) TPACK survey was developed for use with preservice elementary teachers, so revisions were made for the current study, eliminating items pertaining to academic subjects other than mathematics and modifying items that referred to preservice teachers' coursework (see Appendix F). Each item on the survey was scored from 1 (*strongly disagree*) to 5 (*strongly agree*), and all the items in each construct were averaged so that each construct received a score in the range of 1 to 5 (Schmidt et al., 2009a).

Online Apangea Math statistics. Apangea Math tracked statistics for the intervention group including the amount of time each student spent using the online program, how many lessons they completed, and how many lessons they passed.

Design

The design of this study was quasi-experimental because the students were in intact classes. This was a mixed methods study with an emphasis on quantitative data collected through observation forms, surveys, and assessments. These quantitative data were analyzed using SPSS© (Statistical Package for the Social Sciences) software from IBM. The qualitative data was analyzed using QDA Miner© (Qualitative Data Analysis Miner) software from Provalis Research.

To model the design of this experiment, the sequence of events can be represented in symbolic notation: N = non-equivalent group, X = intervention, O₁ = DA tests, O₂ = student engagement survey, O₃ = summary of Apangea Math usage statistics, O₄ = Algebra 1 EOC exam, and O₅ = Anonymous questionnaires. The top row represents the data collected from the comparison group in spring semester of 2011, and the second row represents the data collected from the intervention group in spring semester of 2012:

Comparison Group: N --- O₁ ----- O₁ -- O₄

Intervention Group: N --- O₁, O₂ --- X --- O₁, O₂, O₃ -- O₄, O₅

Two factors in this design, treatment (intervention or comparison) and time (pre or post DAs), were crossed, meaning “each level of each factor appears with each level of the other factor” (Games, 1978, p. 254). The crossed factors are perfectly suited to a conventional factorial design. According to Games, when each level of a factor appears

in only one level of the other, the first factor is said to be nested in the second factor. For example, every student is a member of only one treatment group. Thus, no student experiences both treatments; students are nested within each treatment. Also, some of the teachers taught only one of the two years while others taught in both 2011 and 2012; therefore, some of the teachers represent crossed factors while others are nested within just one treatment. The factors that are nested can contribute to the non-equivalent nature of the groups. Consequently, inferring causation was tempered with caution.

Ethical Considerations

For this study, the Institutional Review Board (IRB) approved the use of student data that had been generated as a part of planned instruction or assessment after the semester ended and it had been de-identified. The IRB also permitted the inclusion of data gathered from the anonymous student and teacher questionnaires, which were administered by school personnel at the conclusion of the intervention period. For the use of the Student Engagement Survey data, which was collected specifically for this study, parent permission forms (see Appendix G) and student assent was required (see Appendix H). Students who returned their signed permission forms had a chance to win one of three \$20 gift cards to a local store. No other incentives were offered for participation and the students' completion of the survey was voluntary. The teachers who implemented the intervention signed informed consent letters (see Appendix I) agreeing to their participation in the study. Confidentiality of participants was ensured by assigning codes to students and creating pseudonyms for teachers.

Analysis Plan

Student achievement analysis plan. The first research question and its sub-question address student achievement:

1. How does student achievement in Algebra 1 differ based on instructional program?

Related sub-question:

- How does student achievement in each of Tennessee's mathematics content standards for Algebra 1, (a) mathematical processes, (b) number and operations, (c) algebra, (d) geometry and measurement, and (e) data analysis, statistics, and probability differ based on instructional program?
- How do student achievement gains differ by instructional treatment based on students' initial skill levels?

The initial analysis of student achievement in mathematics was an independent t test conducted to compare the EOC scores of the test group and the comparison group in order to provide a broad picture of student outcomes. However, since the design of the study was quasi-experimental and the EOC represented absolute achievement, it was not the best measure to examine the effect of the intervention.

The effect of the intervention was more appropriately measured by pre and post DA tests so that the change in student achievement over time could be compared. To do this, a mixed ANOVA was conducted with the between groups independent variable being treatment group (2 levels: intervention and comparison) and the within groups independent variable being time (2 levels: pre and post), and the dependent variable being

the percent correct on the DA tests. This showed if there was an interaction between time and treatment on achievement as well as main effects on achievement (see Table 1).

Table 1. *Analysis Plan for Discovery Assessment Scores*

	Pretest	Posttest	Total
Intervention group	Intervention group pretest	Intervention group posttest	Intervention group total
Comparison group	Comparison group pretest	Comparison group posttest	Comparison group total
	Pretest Total	Posttest total	Total

The assumption of normality of distribution of the dependent variable for each group was checked based on skewness and kurtosis values being between -1 and +1 ((Leech, Barrett, & Morgan, 2008). The Box's *M* test, conducted by SPSS, was used to check the assumption of sphericity.

To answer the sub-question regarding content standards, the effects of instructional treatment on achievement was analyzed in more detail by running a similarly structured mixed ANOVA for each content area of the DA (i.e., mathematical processes, number and operations, algebra, geometry and measurement, and data and statistics). The objective of this analysis was to determine to what extent Apangea Math supported student learning for different content areas of mathematical knowledge.

Next, to answer the sub-question regarding students' initial skill levels, four independent *t*-tests were conducted to determine if the effects of the instructional treatments on achievement gains differed depending on students' initial DA skill level.

The DA skill levels were created by the makers of the DA tests by grouping students into four categories based on their DA scores: less than 28% correct was considered *below basic*, 28 to 42% correct was *basic*, 43 to 58% correct was *proficient*, and 59% or more correct was *advanced*. For each analysis, the data was filtered to select students of a particular initial DA skill level (below basic, basic, proficient, or advanced), then a *t*-test was conducted to determine if the gains made by the intervention group students with that initial DA skill level were significantly different from the gains made by the comparison group students with the same initial DA skill level.

Finally, to explore the possibility that differences in achievement may be dependent on course or teacher, course level and teacher level analyses were conducted. The gains made by Algebra 1 students were compared to that of Algebra 1B students who were taught by the same teacher (Bryce) to determine if gains differed based on course. Independent *t* tests were conducted to determine if the students of each of the teachers who taught both years showed significantly different gains on DAs differed based on instructional treatment group. Also, an ANOVA was conducted on the intervention group students' data to determine how their gains on DAs differed based on teacher.

Student engagement analysis plan. The second research question and its sub-questions address student engagement:

2. How does student engagement in mathematics change after students experience blended learning with Apangea Math?

Related sub-questions:

- How does each construct of student engagement, (a) learning goal, (b) task value, (c) self-efficacy, and (d) self-regulation differ after exposure to the Apangea Math?
- How do teachers, classroom observations, and students rate the engagement of students in Apangea Math?

A student engagement survey was administered to the intervention group students in January (pre) and in April (post) to measure changes in their attitudes towards learning mathematics. To examine how student engagement was affected by Apangea Math, a paired samples *t*-test was conducted to analyze changes in student engagement composite scores over time. Additionally, paired samples *t*-tests were conducted for learning goal, task value, self-efficacy, and self-regulation to determine if exposure to Apangea Math affected changes in these different constructs over time differently. Furthermore, other sources of data, namely, responses to specific items on the implementation and observation form (see Appendix C, participant responsiveness), anonymous student questionnaire (see Appendix D, #4), and teacher questionnaire (see Appendix E, #2) were summarized and analyzed to provide a clear picture of the level of engagement that students experienced while working online with the Apangea Math program.

Implementation and correlations analysis plan. The third research question and its sub-questions address the relationships between the implementation process and student outcomes:

3. How well was Apangea Math implemented in relation to how it was intended to be implemented?

Related sub-questions:

- What challenges do teachers encounter, and what practices do they use when implementing Apangea Math?
- What relationships exist between implementation fidelity and achievement?

The examination of implementation fidelity involved four major components: adherence, exposure, quality of program delivery, and participant responsiveness (Mihalic, 2002). All four of these constructs were rated on teachers' forms weekly and during classroom observation spot-checks (see the first page of Appendix C). Adherence referred to how well the intervention program adhered to the design protocols and best practices when it was implemented. Exposure had to do with the amount of time students spent working online on Apangea Math. Data for exposure came from teachers' estimates of the class time that they allotted for students to access the program and Apangea Math's online statistics which tracked each individual student's usage time on the program. An ANOVA was conducted to determine if students' time on Apangea differed based on teacher. Quality of delivery involved smoothness of technical connectivity, teachers' TPACK knowledge, and teachers' attitudes. The smoothness of technical delivery was rated by teachers weekly and corroborated by classroom observations, and a TPACK survey was administered to gauge the level of the teachers' TPACK knowledge. Participant responsiveness was the extent to which students were engaged and working on Apangea Math. Program responsiveness was measured with the implementation and observation forms, student engagement surveys, and items on the

anonymous questionnaires along with the second research question, which addressed student engagement. To answer the sub-question regarding the roles teachers played when implementing blended learning, data was collected through estimates recorded on teachers' forms weekly and classroom observation spot-checks (see Appendix C, second page), teachers' questionnaires (see Appendix E, #1), and students' questionnaires (see Appendix D, #1-3). Implications from the literature suggested that teachers' increased ability to differentiate instruction when using an ITS program would contribute to positive student outcomes (Harmon, 2011; Schussler, 2009).

Utilizing teachers' self-reported data, questionnaires, and observations are typical methods for collecting data on implementation fidelity (Lendrum & Humphrey, 2012; O'Donnell, 2008). However, Lendrum and Humphrey (2012) described concerns about teachers' self-reported measures of adherence, reporting that teachers' ratings were sometimes negatively correlated with ratings from observers, with the ratings of the observers being more accurate than those of the teachers. O'Donnell (2008) reported that when observations and self-reported data were collected simultaneously, the self-reported data tended to indicate higher levels of fidelity than what was observed.

Teachers have sometimes "experienced a conflict between the need to teach effectively and the need to deliver the curriculum as intended" (Lendrum & Humphrey, 2012, p. 641), which has led them to make well intended adaptations but tend to change the delivery of the intended program, reducing fidelity. Lendrum and Humphrey explained that teachers often seemed less aware than observers regarding the use of adaptations; thus, the ratings of implementation fidelity differed between teachers and

observers. However, in some cases, such adaptations may not be considered to be a lack of fidelity if critical elements of an intervention are not altered because local modifications may improve the fit of the program in a given setting (Lendrum & Humphrey, 2012; Protheroe, 2008). Another reason why teachers' and observers' ratings of implementations fidelity have been incongruent is the subjective nature of rating the components of implementation, such as adherence and quality of delivery (Lendrum & Humphrey, 2012). For these reasons, it was anticipated in this study that some discrepancies between the teachers' and the observations' reports of fidelity of implementation would arise.

The qualitative data about challenges teachers encountered and the teaching practices they used when implementing the blended learning curriculum was collected via teachers' responses to open-ended questions on their weekly forms, classroom observation spot-checks' remarks concerning the same open-ended questions (see Appendix C, second page), and notes taken during teachers' meetings. A Computer Assisted Qualitative Data Analysis Software (CAQDAS) program; namely QDA Miner, was used to analyze the qualitative data. CAQDAS can provide the advantages of increased rigor, additional analysis options, and a clear audit trail (Seale, 2010). The data about challenges and practices were coded and recoded in an iterative process to reveal themes that emerged. The data was also categorized as first-order (external) or second-order (internal) according to the Snoeyink and Ertmer (2001) framework.

After variables concerning the implementation were documented, correlational analyses were conducted to determine if there were significant relationships between the

implementation, student engagement, and student achievement data. Multiple regressions were conducted to determine an equation for predicting EOC scores.

Correlations were analyzed in an effort to determine if they provided evidence to verify theories that supported the notion that using Apangea Math should increase student engagement and improve student achievement. Gravetter and Wallnau (2011) described this type of theory verification saying, “In each case, the prediction of the theory could be tested by determining the correlation between the two variables” (p. 477). For example, in this study, it was theorized that a change in the dosage of treatment would result in a change in outcome (Trochim & Land, 1982); thus, an increase in the number of hours that students spent with the ITS program was expected to correlate with increased achievement. It was also theorized that increased student engagement leads to increased academic achievement (Reigeluth, 2011), so a correlation was expected between engagement scores and achievement.

Caution was used when attempting to infer causation with these statistical tests because using the ANOVA results to infer causation is particularly risky when the design of the study was quasi-experimental (Stevens, 2007). Also, correlations describe simple relationships between two variables, but they are not capable of explaining why the correlation exists, so proof of causation is not possible (Gravetter & Wallnau, 2011).

Summary of Methodology

A positivist epistemology shaped the methodology of this study; thus, the data collected was primarily quantitative. However, some qualitative data was included to reveal details about the implementation process of the technology-based intervention.

Based on Fleischman and William's evaluation framework (1996), outcomes of the intervention were examined to determine to what extent the intervention contributed to changes in student engagement and achievement, and the implementation process was studied in order to identify what may have contributed to those outcomes. The frameworks used to analyze the implementation were Mihalic's (2002) four primary components of fidelity of implementation and Snoeyink and Ertmer's (2001) categorization of change as first-order (external) or second-order (internal). When analyzing relationships between variables, correlations were viewed as contributing to outcomes as opposed to being viewed as causal.

Chapter 4

Results

Student Achievement Findings

Students in this study were arranged in intact classes. The intervention group students took Algebra 1 or Algebra 1B in spring semester of 2012, receiving a blended learning curriculum including Apangea Math and face-to-face instruction. The comparison group students took Algebra 1 or Algebra 1B in spring semester of 2011, receiving face-to-face instruction alone. Absolute student achievement demonstrated on Algebra 1 EOC exams was examined to compare the performance of the intervention group and the comparison group. However, because this was a quasi-experimental design, a more appropriate measure of the effect of the intervention came from the analysis of the change in student achievement over time based on pre and post DA tests.

Algebra 1 EOC Exams. Seventy-four intervention group students and 99 comparison group students took the Algebra 1 EOC exam. Note that one of the original 75 intervention group students moved and withdrew from the high school about a week before the administration of the EOC exam. To determine whether the two groups differed in their final mathematics achievement based on EOC quick scores, a *t*-test was conducted. The assumption of normality was checked by examining the skewness and kurtosis of the dependent variable for each group. The intervention group scores were skewed negatively slightly (-1.20) while all other measures of skewness and kurtosis for the two groups' EOC scores were between -1 and 1. This minor violation of the

assumption of normality was ignored because two-tailed t tests are robust, meaning the slight skewness was not expected to cause a change in the test's outcome (Leech, et al., 2008). The assumption of homogeneity of variances was checked, and the Levene's test indicated that the assumption had been violated; therefore, the portion of the SPSS output that applies to situations when equal variances are not assumed was used. There was a statistically significant difference between the intervention group and the comparison group on EOC quick scores, $t(170.96) = 5.92, p < .001, d = .88$. Intervention group students ($M = 82.65, SD = 10.95$) scored significantly higher than comparison group students ($M = 71.21, SD = 14.45$), and the effect size was larger than typical (Leech, et al., 2008). The confidence interval for the difference between the means was 7.63 to 15.25 indicating that if the study were repeated 100 times, for 95 of those times the difference in the gains between the intervention group and the comparison group would fall between 7.63 points and 15.25 points. From a practical standpoint, these differences are important because they are large enough to change the performance levels by which students and schools are judged. An EOC quick score that is less than 70 falls into the *below basic* performance level, 70 to 84 is *basic*, 85 to 92 is *proficient*, and 93 to 100 is *advanced*. Students who score at the below basic level are required to retake the Algebra 1 course. Students who score at the basic level pass the course individually but are not counted favorably for the school. According to NCLB rules, the school is judged based on the percentage of students who score at proficient or advanced levels. Table 2 shows the number of students and the percent of students who scored at each performance level by instructional treatment group.

Table 2. *Performance Levels on Algebra 1 EOC exam by Group*

Performance Levels on EOC exam	Below Basic <i>n</i> (%)	Basic <i>n</i> (%)	Proficient <i>n</i> (%)	Advanced <i>n</i> (%)	Total <i>n</i> (%)
Intervention Group	7 (9.5%)	27 (36.5%)	27 (36.5%)	13 (17.5%)	74 (100%)
Comparison Group	31 (31.3%)	52 (52.5%)	11 (11.1%)	5 (5.1%)	99 (100%)

Fifty-four percent of the intervention group students scored proficient or advanced while only 16.2% of the comparison group scored proficient or advanced. The percent of ninth grade Algebra 1 students who scored proficient or advanced in the intervention group was more than triple the percent who scored at those performance levels in the comparison group. Thirty-one students in the comparison group had to repeat the course while only seven students in the intervention group were required to repeat.

Discovery Assessments. Sixty-seven of the intervention group students and 92 of the comparison group students were present for both the January (pre-test) and the April (post-test) administrations of the DA tests. Table 3 shows the number of students, the means, and standard deviation for the percent correct on DA tests as a function of time and treatment group.

When examining these DA scores, it became apparent that the intervention group's pre-test scores ($M = 42.54$, $SD = 13.50$) were considerably higher than the comparison group's pre-test scores ($M = 33.67$, $SD = 10.55$), reaffirming the importance of evaluating the effects of the intervention based on achievement gains rather than on

Table 3. Means and Standard Deviation for Discovery Assessments by Time and Group

DA Scores	<i>n</i>	Pre-test		Post-test		Total	
		<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Intervention Group	67	42.54	(13.50)	51.99	(15.74)	47.26	(15.36)
Comparison Group	92	33.67	(10.55)	38.32	(13.21)	35.99	(12.15)
Total	159	37.41	(12.63)	44.08	(15.81)	40.74	(14.67)

absolute outcomes. From pre-test to post-test the intervention groups' mean score went up from 42.54 to 51.99, an increase of 9.45 points. The comparison group's scores went up from 33.67 to 38.32, an increase of 4.65 points. The profile plot depicted in Figure 2 shows the change in the DA Scores over time for the intervention group and the comparison group.

A mixed ANOVA was conducted to determine if there were statistically significant differences in the DA scores based on the within-subjects independent variable, time (pre-test or post-test), or the between-subjects independent variable, group (intervention or comparison), and to see if there was a significant interaction effect between time and treatment on DA scores.

The assumptions of normality and sphericity were met. Results indicated a significant main effect of time, a significant main effect of group, and a significant interaction effect between time and group. The significant main effect of time, $F(1,157)$

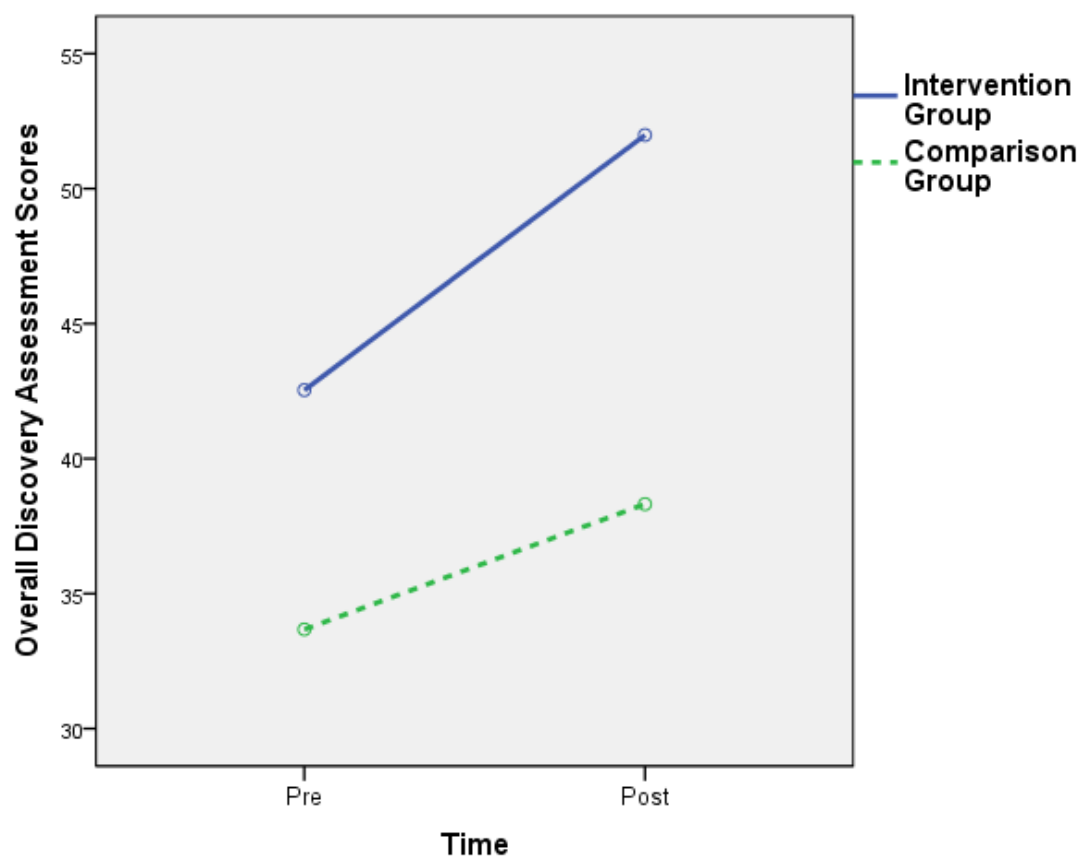


Figure 2. Discovery Assessment scores over time by treatment group.

= 45.12, $p < .001$, partial $\eta^2 = .223$, showed overall post-test scores ($M = 37.41$, $SD = 12.63$) were significantly higher than pre-test scores ($M = 44.08$, $SD = 15.81$) among all students. The significant main effect of group, $F(1,157) = 37.70$, $p < .001$, partial $\eta^2 = .194$, revealed that the intervention group ($M = 47.26$, $SD = 15.36$) scored significantly higher than the comparison group ($M = 35.99$, $SD = 12.15$) across the two administrations of the test. More importantly, the significant interaction effect between time and group, $F(1,157) = 5.25$, $p < .05$, partial $\eta^2 = .032$, observed power = .63, indicated that from pre to post DA the intervention group's gains (9.45 points) were significantly greater than the comparison group's gains (4.65 points). The eta for the interaction effect was about .18 ($\sqrt{.032} = .18$), which is a small to medium effect size (Leech, et al., 2008). The changes in percent correct for each content area on the DA tests (i.e., Mathematical Processes, Numbers and Operations, Algebra, Geometry and Measurement, and Data Analysis, Statistics, and Probability) were examined to determine if the changes in each area differed based on instructional treatment. See Figure 3 for a pictorial representation of pre and post DA test scores by treatment group and content area.

A mixed ANOVA was conducted to determine if there were statistically significant differences in the percent students' answered correctly for each content area based on time or treatment group and to see if there was a significant interaction effect between time and treatment on the scores. The assumptions of normality and sphericity were checked and met for each mixed ANOVA.

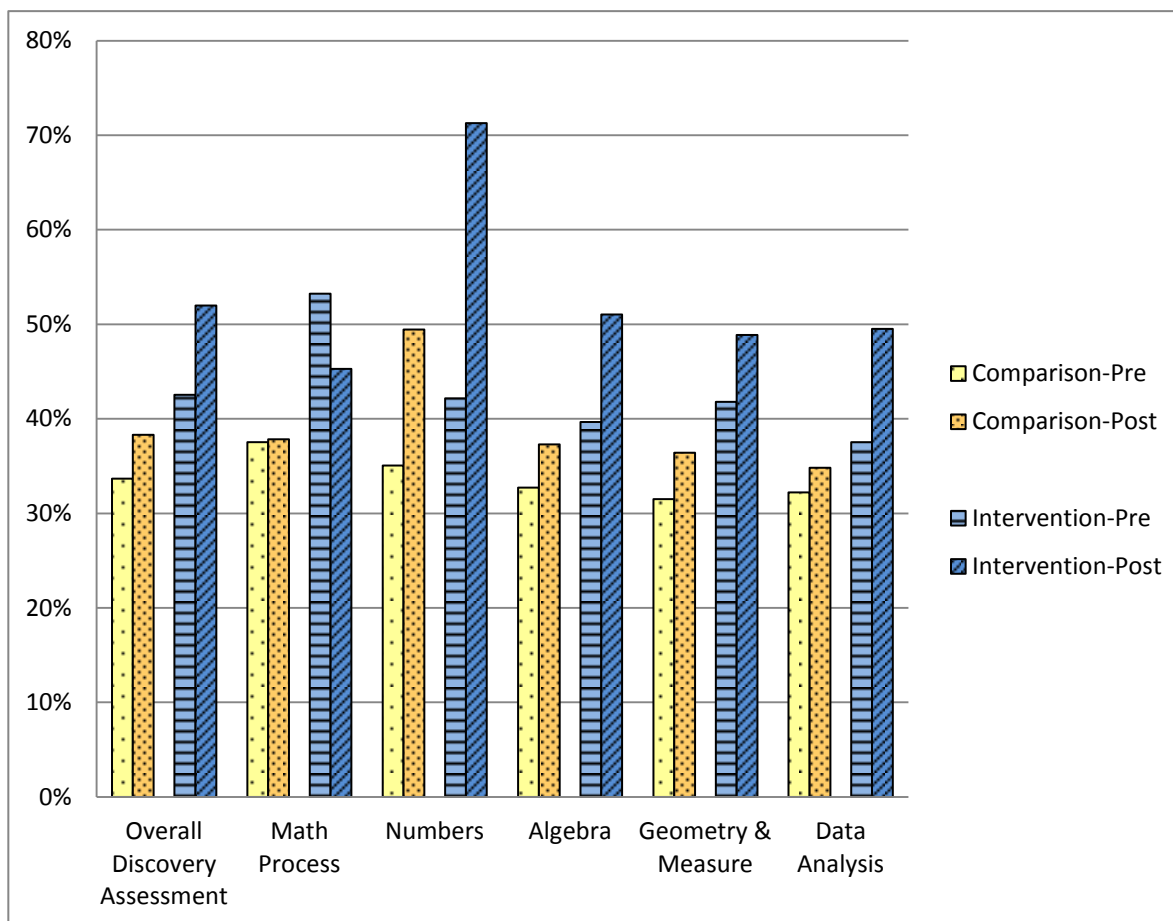


Figure 3. Pre and post DA test scores by content area for the comparison and intervention groups.

Mathematical Processes. Examination of the Math Processes scores revealed that this was the only content area in which the intervention group's post-test scores ($M = 45.28$, $SD = 26.87$) were lower than their pre-test scores ($M = 53.24$, $SD = 23.56$). The comparison group's scores in mathematical processes from pre-test ($M = 37.52$, $SD = 20.20$) to post-test ($M = 37.85$, $SD = 22.10$) remained practically unchanged. Table 4 shows the number of students, the mean, and standard deviation for the content area, Mathematical Processes, as a function of time and treatment group.

Table 4. *Means and Standard Deviation for Mathematical Processes by Time and Group*

Mathematical Processes Scores	<i>n</i>	Pre-test		Post-test		Total	
		<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Intervention Group	67	53.24	(23.56)	45.28	(26.87)	49.26	(25.49)
Comparison Group	92	37.52	(20.20)	37.85	(22.10)	37.68	(21.11)
Total	159	44.14	(22.97)	40.98	(24.42)	42.56	(23.72)

Results of the mixed ANOVA indicated a significant main effect of group, $F(1,157) = 14.62$, $p < .001$, partial $\eta^2 = .085$, but not of time, $F(1,157) = 3.26$, $p = .073$, partial $\eta^2 = .020$. These main effects indicated that, for mathematical processes, the intervention group's scores ($M = 49.26$, $SD = 25.49$) overall were significantly higher than the comparison group's scores ($M = 37.68$, $SD = 21.11$), but the overall pre-test scores ($M = 44.14$, $SD = 22.97$) and post-test scores ($M = 40.98$, $SD = 24.42$) did not

differ significantly. Furthermore, the interaction effect between time and group on Math Processes scores was not significant, $F(1,157) = 3.85$, $p = .052$, partial $\eta^2 = .024$, indicating that the difference between the 7.96 point loss made by the intervention group and the 0.33 point gain made by the comparison group had more than a 5% probability of happening by chance.

Numbers and Operations. The number of students, the mean, and standard deviation for the content area, Numbers and Operations, as a function of time and treatment group are shown on Table 5.

Table 5. *Means and Standard Deviation for Number and Operation by Time and Group*

Numbers and Operations Scores	<i>n</i>	Pre-test		Post-test		Total	
		<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Intervention Group	67	42.16	(27.25)	71.27	(26.20)	56.72	(30.37)
Comparison Group	92	35.05	(24.88)	49.46	(28.94)	42.26	(27.87)
Total	159	38.05	(26.06)	58.65	(29.77)	48.35	(29.77)

The results of the mixed ANOVA indicated a significant main effect of time, $F(1,157) = 62.35$, $p < .001$, partial $\eta^2 = .284$, meaning the post-test scores ($M = 58.65$, $SD = 29.77$) in Numbers and Operations were significantly higher than pre-test scores ($M = 38.05$, $SD = 26.06$) among all students. There was also a significant main effect of group, $F(1,157) = 18.93$, $p < .001$, partial $\eta^2 = .108$, revealing that the intervention

group ($M = 56.72$, $SD = 30.37$) scored significantly higher than the comparison group ($M = 42.26$, $SD = 27.87$) in this content area overall. More importantly, there was a significant interaction effect between time and group, $F(1,157) = 7.12$, $p < .01$, partial $\eta^2 = .043$, indicating that the intervention group's gain of 29.11 points in the area of Numbers and Operations was significantly greater than the comparison group's gain of 14.41 points in this content area. The eta for this interaction effect was about .21 ($\sqrt{.043} = .21$), which is slightly less than a medium effect size (Leech, et al., 2008).

Algebra. Table 6 shows the means and standard deviation for the percent correct in the content area, Algebra, as a function of time and treatment group. For the content

Table 6. *Means and Standard Deviation for Algebra by Time and Group*

Algebra Scores	<i>n</i>	Pre-test		Post-test		Total	
		<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Intervention Group	67	39.66	(14.63)	51.03	(17.50)	45.34	(17.05)
Comparison Group	92	32.74	(12.62)	37.29	(17.14)	35.01	(15.18)
Total	159	35.65	(13.89)	43.08	(18.53)	39.36	(16.77)

area, Algebra, the mixed ANOVA indicated a significant main effect of time, $F(1,157) = 27.03$, $p < .001$, partial $\eta^2 = .147$, meaning the post-test scores ($M = 43.08$, $SD = 18.53$) for the Algebra portion of the DAs were significantly higher than pre-test scores ($M = 35.65$, $SD = 13.89$) for both treatment groups overall. There was also a significant main

effect of group, $F(1,157) = 27.62, p < .001$, partial $\eta^2 = .150$, showing that the intervention group ($M = 45.34, SD = 17.05$) scored significantly higher than the comparison group ($M = 35.01, SD = 15.18$) in this content area overall. Additionally, there was a significant interaction effect between time and group, $F(1,157) = 4.95, p < .05$, partial $\eta^2 = .031$, indicating that for the content area of Algebra the intervention group's gain of 11.37 points was significantly greater than the comparison group's gain of 4.55 points. The eta for this interaction effect was about .18 ($\sqrt{.031} = .18$), which is a small to medium effect size (Leech, et al., 2008).

Geometry and Measurement. The means and standard deviations for the content area, Geometry and Measurement, by time and group are shown in Table 7. The results of the mixed ANOVA for Geometry and Measurement indicated a significant main effect of time, $F(1,157) = 5.14, p < .05$, partial $\eta^2 = .032$, meaning the post-test

Table 7. *Means and Standard Deviation for Geometry and Measurement by Time and Group*

Geometry and Measurement Scores	<i>n</i>	Pre-test		Post-test		Total	
		<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Intervention Group	67	41.79	(25.52)	48.88	(27.32)	45.34	(26.58)
Comparison Group	92	31.52	(26.69)	36.41	(26.05)	33.97	(26.42)
Total	159	35.85	(26.61)	41.67	(27.22)	38.76	(27.04)

scores ($M = 41.67$, $SD = 27.22$) for this content area were significantly higher than pre-test scores ($M = 35.85$, $SD = 26.61$) overall. There was also a significant main effect of group, $F(1,157) = 11.75$, $p < .01$, partial $\eta^2 = .070$, revealing that the intervention group ($M = 45.34$, $SD = 26.58$) scored significantly higher than the comparison group ($M = 33.97$, $SD = 26.42$) in Geometry and Measurement throughout the study. However, the interaction effect between time and group was not significant, $F(1,157) = 0.17$, $p = .678$, partial $\eta^2 = .001$, indicating that in this content area the intervention group's gain of 7.09 points was not significantly different than the comparison group's gain of 4.89 points.

Data Analysis, Statistics, and Probability. For Data Analysis, Statistics, and Probability, the means and standard deviations by time and group are shown in Table 8.

Table 8. *Means and Standard Deviation for Data Analysis, Statistics, and Probability by Time and Group*

Data Analysis, Statistics, and Probability Scores	<i>n</i>	Pre-test		Post-test		Total	
		<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Intervention Group	67	37.54	(22.49)	49.52	(24.62)	43.53	(24.25)
Comparison Group	92	32.23	(19.24)	34.82	(21.88)	33.52	(20.62)
Total	159	34.47	(20.77)	41.01	(24.12)	37.73	(22.77)

The mixed ANOVA indicated a significant main effect of time, $F(1,157) = 10.46, p < .01$, partial $\eta^2 = .062$, meaning the post-test scores ($M = 41.01, SD = 24.12$) for Data Analysis, Statistics, and Probability were significantly higher than pre-test scores ($M = 34.47, SD = 20.27$) overall. There was also a significant main effect of group, $F(1,157) = 13.73, p < .001$, partial $\eta^2 = .080$, showing that the intervention group ($M = 43.53, SD = 24.25$) scored significantly higher than the comparison group ($M = 33.52, SD = 20.62$) in this content area across time. Additionally, there was a significant interaction effect between time and group, $F(1,157) = 4.35, p < .05$, partial $\eta^2 = .027$, indicating that the intervention group's gain of 11.98 points was significantly greater than the comparison group's gain of 2.59 points. The eta for this interaction effect was about .16 ($\sqrt{.027} = .16$), which is a small effect size (Leech, et al., 2008). A summary of the means and standard deviations, significance, and effect sizes for the comparison of intervention and comparison groups' student achievement findings are displayed in Table 9.

Table 9. *Summary of Achievement Data by the Intervention and Comparison Groups*

	Intervention Group		Comparison Group		Sig.	Effect Size
	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>		
Algebra 1 EOC Quick Scores	82.65	(10.95)	71.21	(14.45)	$p < .001$	.88

		Intervention Group		Comparison Group		Interaction Effect Time * Group	Effect Size
		<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>	Sig.	
Percent Correct							
Discovery Assessment	Pre	42.54	(13.50)	33.67	(10.55)	$p < .05$	.18
	Post	51.99	(15.74)	38.32	(13.21)		
Math Processes	Pre	53.24	(23.56)	37.52	(20.20)	ns	.15
	Post	45.28	(26.87)	37.85	(22.10)		
Numbers & Operations	Pre	42.16	(27.25)	35.05	(24.88)	$p < .01$	.21
	Post	71.27	(26.20)	49.46	(28.94)		
Algebra	Pre	39.66	(14.63)	32.74	(12.62)	$p < .05$	.18
	Post	51.03	(17.50)	37.29	(17.14)		
Geometry & Measurement	Pre	41.79	(25.52)	31.52	(26.69)	ns	.03
	Post	48.88	(27.33)	36.41	(26.05)		
Data Analysis, Stats & Prob.	Pre	37.54	(22.49)	32.23	(19.24)	$p < .05$	.16
	Post	49.52	(24.62)	34.82	(21.88)		

Aptitude level analyses of achievement gains. Did the difference in achievement gains by treatment depend on students' initial DA skill level? Students' initial DA skill level, which was determined by their DA pre-test scores, was a measure of their aptitude. Table 10 displays the means and standard deviations for DA gains made by intervention and comparison group students based on their initial DA skill levels. The table shows that for both instructional treatment groups the achievement gains were highest among the students whose initial DA skill level was below basic.

Table 10. *Means and Standard Deviations for DA Gains by Group and Initial DA skill level*

DA Skill Level	Intervention Group			Comparison Group		
	<i>n</i>	<i>M</i>	(<i>SD</i>)	<i>n</i>	<i>M</i>	(<i>SD</i>)
Advanced	8	5.25	(11.41)	1	-13.00	
Proficient	25	8.04	(9.97)	8	-1.25	(18.77)
Basic	26	7.46	(13.67)	51	1.98	(12.25)
Below Basic	8	24.50	(11.47)	32	10.91	(10.79)
Total	67	9.45	(12.91)	92	4.65	(13.17)

Independent *t*-tests were conducted to determine if the gains made by the intervention group students were significantly different from the gains made by the comparison group students at each initial DA skill level (below basic, basic, proficient, and advanced). Among students who had initial DA skill levels of below basic, the

intervention group students' DA gains ($M = 24.50$, $SD = 11.46$) were significantly greater than the comparison group's gains ($M = 10.91$, $SD = 10.79$), $t(38) = 3.15$, $p < .01$.

However, among students who had initial DA skill levels of basic, the intervention group students' DA gains ($M = 7.46$, $SD = 13.67$) were not significantly different from the comparison group's gains ($M = 1.98$, $SD = 12.25$), $t(75) = 1.79$, $p = .078$. Likewise, among students who had initial DA skill levels of proficient, the intervention group students' DA gains ($M = 8.04$, $SD = 9.97$) were not significantly different from the comparison group's gains ($M = -1.25$, $SD = 18.77$), $t(31) = 1.83$, $p = .077$. No analysis was conducted on the students whose initial DA skill level was advanced because the comparison group's sample size was inadequate.

Course level analyses of achievement gains. Did gains made by intervention group students depend on which course students were enrolled in, Algebra 1 or Algebra 1B? Of the eight intervention group classes, seven were enrolled in the Algebra 1B course and one was enrolled in the Algebra 1 course. Therefore, it was relevant to compare the DA gains made by intervention group students based on course. Descriptive statistics showed that the means for gains made from pre to post DA tests for the 67 intervention group students who took both administrations of the test was 9.45 points, 9.67 points for the 61 Algebra 1B students, and 7.17 points for the six Algebra 1 students. Furthermore, an independent t -test was conducted to compare the gains made by the Algebra 1 and Algebra 1B students who were taught by the same teacher (Bryce). The results indicated that for Bryce's intervention group students, the mean of the Algebra 1

students' gains (7.17 points) did not differ significantly from that of the Algebra 1B students' (5.00 points), $t(11) = .37, p = .717$.

Teacher level analyses of achievement gains. For the teachers who taught both intervention and comparison groups, how did their students' gains differ based on group? Akira and Bryce taught ninth grade Algebra 1 during both the intervention and the comparison periods. Therefore, independent t -tests were conducted for each of those teachers to compare the gains their students made from pre to post DA tests based on instructional treatment group. For Akira, intervention group students' gains ($M = 10.48, SD = 12.28$) were significantly greater than comparison students' gains ($M = 0.52, SD = 13.42$), $t(46) = 2.65, p < .05$. For Bryce, intervention group's gains ($M = 6.00, SD = 10.08$) were not significantly different from the comparison group's gains ($M = 5.00, SD = 12.75$), $t(34) = 0.24, p = .810$.

Did gains made by intervention group students depend on which teacher taught them, Akira, Bryce, Cameron, or Drew? Table 11 displays the mean and standard deviations for the DA scores for the intervention group students by teacher. A mixed ANOVA was conducted to determine if the change in DA scores over time for intervention group students depended on which teacher taught their class. The within-subjects independent variable was time (pre-test or post-test), and the between-subjects independent variable was teacher (Akira, Bryce, Cameron, or Drew). The assumptions of normality and sphericity were met, and results indicated a significant main effect of time, $F(1,3) = 32.23, p < .001$, partial $\eta^2 = .338$, indicating that for all teachers combined, the intervention group's post-test scores ($M = 51.99, SD = 15.74$) were significantly higher

Table 11. Means and Standard Deviations for Intervention Group by Time and Teacher

Intervention Group DA Scores	<i>n</i>	Pre-test		Post-test		Total	
		<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Akira	21	38.29	(13.32)	48.76	(14.12)	43.52	(14.56)
Bryce	13	56.54	(12.38)	62.54	(16.20)	59.54	(14.45)
Cameron	25	42.00	(9.55)	50.80	(14.78)	46.40	(13.09)
Drew	8	32.63	(10.17)	47.00	(17.24)	39.81	(15.56)
Total	67	42.54	(13.50)	51.99	(15.74)	47.26	(15.36)

than their pre-test scores ($M = 42.54$, $SD = 13.50$). There was also a significant main effect of teacher, $F(1,3) = 6.52$, $p < .01$, partial $\eta^2 = .237$, revealing that overall DA scores differed significantly by teacher. The Bonferroni post hoc tests showed that the overall DA scores of Bryce's students ($M = 59.54$, $SD = 14.45$) were significantly higher than that of Akira's students ($M = 43.52$, $SD = 14.56$), Cameron's students ($M = 46.40$, $SD = 13.09$), and Drew's students ($M = 39.81$, $SD = 15.56$). It was reasonable that the overall means of Bryce's intervention students' scores were higher than the other teacher's students because one of Bryce's classes was the one class of Algebra 1 students while all the other classes were Algebra 1B students. The more important result in this analysis was the interaction effect between time and teacher, which was not significant, $F(1,3) = 0.76$, $p = .524$, partial $\eta^2 = .035$, indicating that the gains made by students from pre to post DA test did not differ significantly by teacher. See Figure 4 for a

pictorial representation of the gains made by intervention group students from pre to post DA test by teacher. The means of the DA gains by teacher from lowest to highest were 6.00 points for Bryce, 8.80 for Cameron, 10.48 for Akira, and 14.37 for Drew.

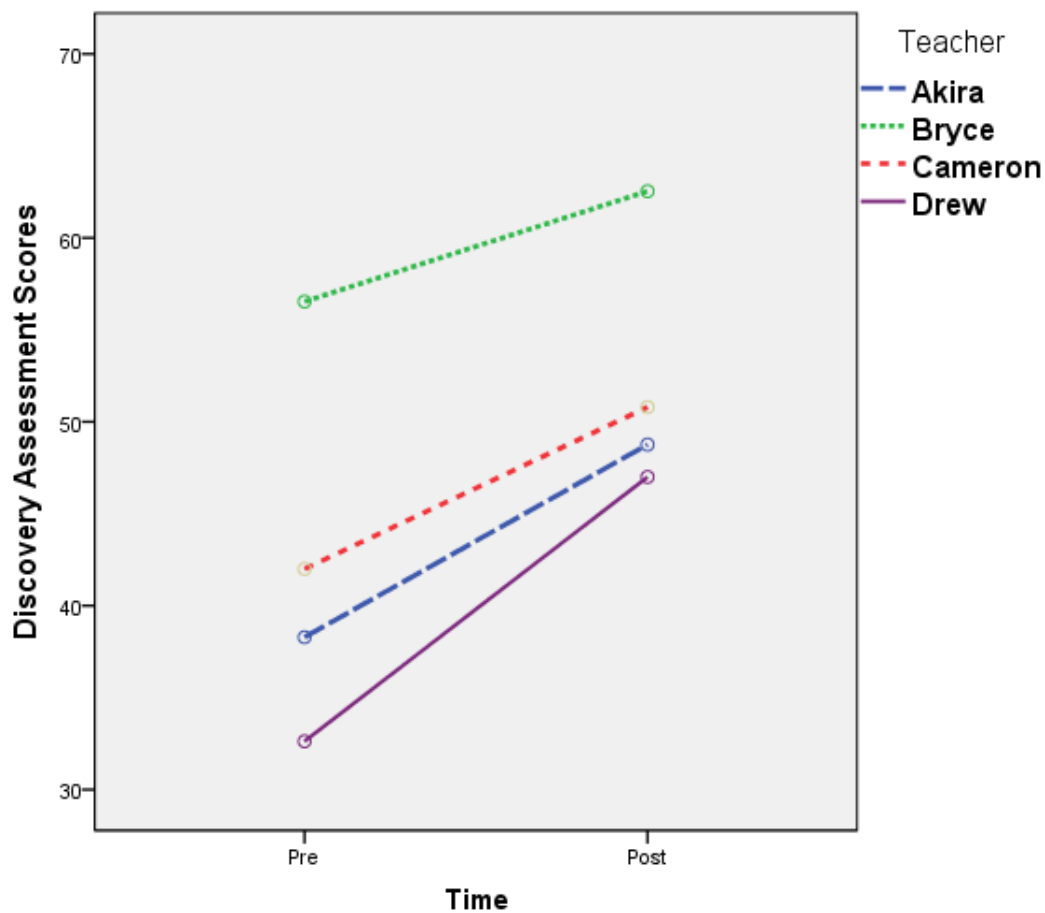


Figure 4. Intervention group scores from pre to post Discovery Assessment by teacher.

Student Engagement Findings

The student engagement of the intervention group was measured in multiple ways. Student engagement surveys were administered in January (pre-test) and in April (post-test). Teachers completed weekly implementation and observation forms, which were supplemented by spot-check classroom observations. Furthermore, both the intervention group students and their teachers completed anonymous multiple choice questionnaires at the end of the semester which included items about engagement.

Student engagement surveys. Thirty-six students, 11 male and 15 female, out of the 75 intervention group students turned in signed parent permission forms to participate in the study and completed both the pre and the post student engagement surveys. The student engagement survey contained 32 items (eight items for each of four constructs). Each item was answered on a five-point scale from 1 to 5; thus, the possible range of scores for each construct was from 5 to 40 and the possible range for the student engagement composite score was 20 to 160. Table 12 shows the means and standard deviation for the composite scores and construct sub-scores by time (pre and post). The means and standard deviations for the composite student engagement survey scores and each of its constructs were practically unchanged from pre to post survey. Paired samples *t*-tests were conducted, which confirmed that none of the differences from pre to post student engagement survey were statistically significant.

Furthermore, subgroup analyses were conducted to see if changes in student engagement differed based on gender or aptitude. A mixed ANOVA was conducted to

Table 12. Means and Standard Deviations for Student Engagement Surveys by Time

	Pre-survey		Post-survey	
	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Composite Student Engagement	133.00	(13.43)	133.25	(12.58)
Learning Goal	37.11	(2.74)	37.53	(2.64)
Task Value	31.97	(3.73)	32.36	(3.49)
Self-Efficacy	32.92	(4.63)	32.44	(4.75)
Self-Regulation	31.00	(5.55)	30.92	(5.68)

determine if there was a significant interactive effect between time (pre to post-survey) and gender. Results showed that there were no significant main effects of time or gender, and there was no significant interactive effect of time and gender on student engagement. Similarly, a mixed ANOVA was conducted to determine if there was a significant interactive effect between time (pre and post-survey) and initial DA skill level (below basic, basic, proficient, and advanced). Results indicated that there were no significant main effects of time or initial DA skill level, and there was no significant interactive effect of time and initial DA skill level on student engagement.

Implementation and observation forms. On a weekly basis during the spring semester of 2012, the teachers of the intervention group students completed implementation and observation forms which included recording a rating for participant responsiveness towards Apangea Math on a scale of 1 (*most students were not engaged*;

they were not working in the program) to 5 (*all students were engaged and working in the program*). Throughout the semester, spot-check classroom observations (2 or 3 per class) were conducted, and during each spot-check, an observation and implementation form was completed. See Appendix C for a copy of the implementation and observation form that was completed by teachers weekly and during spot-check classroom observations. The means and standard deviation for participant responsiveness ratings recorded by teachers and during observations are shown on Table 13.

Table 13. *Means and Standard Deviation for Ratings of Participant Responsiveness*

Participant Responsiveness Ratings (from 1 to 5)	Teachers' Weekly Forms		Classroom Observation Spot-Checks	
	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>
Teacher				
Akira	4.21	(.59)	3.00	(.00)
Bryce	4.00	(.46)	3.67	(1.15)
Cameron	3.78	(.44)	4.00	(.00)
Drew	3.80	(.54)	4.75	(.50)
Total	3.93	(.52)	4.00	(.94)

The means for the teachers' ratings of participant responsiveness ranged from 3.78 to 4.21, while the classroom observation ratings for the same construct ranged from 3.00 to 4.75. The means of two of the teachers' ratings (Bryce and Cameron) were similar to those of classroom observations. However, an independent *t*-test revealed that

Akira rated participant responsiveness of students ($M = 4.21$, $SD = .59$) significantly higher than the ratings they received during classroom observations ($M = 3.00$, $SD = .00$), $t(7) = 5.85$, $p < .01$. Conversely, Drew rated participant responsiveness of students ($M = 3.80$, $SD = .54$) significantly lower than ratings received from classroom observations ($M = 4.75$, $SD = .50$), $t(12)$, $p < .05$. Despite the differences between some of the teachers' ratings and their corresponding classroom observation ratings, the overall mean of all teachers' ratings for participant responsiveness was similar to that of all classroom observations. The mean of all teachers' ratings was 3.93 and the mean of all classroom observation ratings was 4.00, indicating that overall student responsiveness was between 3 (*half of the students were engaged and working in the program*) and 5 (*all students were engaged and working in the program*).

Anonymous questionnaires. The item on the anonymous student questionnaire that specifically addressed student engagement was #4, "When working in Apangea, I was concentrating deeply on the math in the lessons." Students responded to this statement using a five-point scale where 1 = *strongly disagree*, 2 = *disagree*, 3 = *not sure*, 4 = *agree*, and 5 = *strongly agree*. Sixty-two intervention students completed the questionnaire, and more students either agreed or strongly agreed (42%) than disagreed or strongly disagreed (31%) with this statement. The remaining 27% responded "not sure."

The anonymous teacher questionnaire was completed by three of the four intervention group teachers, and item #2 asked teachers directly about student engagement with this multiple choice question:

“How would you describe the overall student responsiveness to Apangea from January to April 2012?”

- None of my students experienced times when they were engaged in the flow of the lessons in Apangea.
- Only a few of my students experienced times when they were engaged in the flow of the lessons in Apangea.
- About half of my students experienced times when they were engaged in the flow of the lessons in Apangea.
- Most of my students experienced times when they were engaged in the flow of the lessons in Apangea.
- All of my students experienced times when they were engaged in the flow of the lessons in Apangea.

One of the teachers chose “About half of my students...were engaged” and two selected “Most of my students...were engaged.”

Implementation and Correlations

Fidelity of implementation. There are four major components in examining fidelity of implementation: adherence, exposure, quality of program delivery, and participant responsiveness (Mihalic, 2002). The following protocols for students accessing Apangea were established:

- Headphones – Students should wear headphones during Apangea to hear interactive lesson.

- Paper and pencil – Students should use paper and pencil to take notes during the interactive lessons and to work out problems in Apangea. (Note: initially, the students’ papers were referred to as worksheets and they were collected; however, teachers later agreed to dispense with the practice of collecting the papers, but students were still expected to use scratch paper to work out problems.)
- Calculators – Students should use the classroom calculators (the ones they use for EOC’s) while doing Apangea Math in class, but they should know that there is a calculator (along with formulas and definitions of math words) in the Apangea Math online toolbox to be used when they are not in class.
- Time – Students should get at least 30 to 40 minutes of uninterrupted time working in Apangea Math per session to get into a flow.

Adherence. Adherence is a construct by which actual program implementation is compared to its design protocols. The teachers and the classroom observation spot-checks recorded ratings for students’ adherence to Apangea Math on the implementation and observation forms using a scale of 1 (*only a few students accessed the program or only a few used headphones or calculators or paper*) to 5 (*all the students accessed the program and all used headphones, calculators, and paper*). Table 14 displays the means and standard deviation for adherence ratings recorded by teachers and during classroom observations.

Table 14. Means and Standard Deviation for Ratings of Adherence

Adherence Ratings (from 1 to 5)	Teachers' Weekly Forms		Classroom Observation Spot-Checks	
	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>
Teacher				
Akira	4.41	(.47)	3.50	(.71)
Bryce	3.88	(.52)	3.33	(.58)
Cameron	4.22	(.71)	4.00	(.00)
Drew	3.95	(.16)	3.75	(.50)
Total	4.11	(.52)	3.60	(.52)

For adherence, the means for the teachers' ratings ranged from 3.88 to 4.41, while the classroom observation ratings ranged from 3.33 to 4.00. A one-way ANOVA revealed teachers' ratings of adherence did not differ significantly from one another. For all four teachers, classroom observations reported lower ratings for adherence than the teachers self-reported; however, *t*-tests indicated that none of the means of the classroom observations were statistically significantly different from those of the teachers. The mean of teachers' ratings was 4.11 and the mean of all classroom observation ratings was 3.60, indicating that overall student responsiveness was between 3 (*approximately half of the students accessed the program and most of them used headphones, calculators, and paper*) and 5 (*all the students accessed the program and all used headphones, calculators, and paper*).

Exposure. As a measure of exposure, the teachers estimated the class time that they provided for students to access Apangea Math on the weekly implementation and observation forms where 1 = *less than 40 minutes per week*, 2 = *41 to 80 minutes per week*, 3 = *81 to 120 minutes per week*, 4 = *121 to 160 minutes per week*, and 5 = *more than 161 minutes per week*. Students' actual exposure to Apangea Math was measured by online Apangea Math statistics which recorded each student's time on the program. The means and standard deviations for teachers' estimates of exposure and students' actual time on the program by teacher are shown on Table 15. The means of the teachers' ratings of exposure ranged from 3.31 to 4.10, which translates to approximately 93 min (or 1.6 hours) to 125 min (2.1 hours). A one-way ANOVA revealed that teachers' ratings of exposure did not differ significantly from one another.

Table 15. *Means and Standard Deviation for Exposure*

Measures of Exposure Teacher	Teachers' Weekly Exposure Ratings		Students' Total Time on Apangea in hours	
	<i>M (SD)</i>	hrs/wk	<i>M (SD)</i>	hrs/wk
Akira	3.56 (1.59)	1.7	15.43 (3.64)	1.3
Bryce	3.31 (0.75)	1.6	13.06 (5.77)	1.1
Cameron	3.56 (0.88)	1.7	11.49 (3.07)	1.0
Drew	4.10 (0.57)	2.1	17.43 (1.99)	1.5
Total	3.65 (1.02)	1.8	13.61 (4.34)	1.1

The mean of all the teachers' ratings was 3.65 which indicating that overall they estimated that students accessed Apangea Math in class for approximately 107 min (or 1.8 hours) per week. The online Apangea Math statistics showed that the means for the number of hours that students spent using Apangea Math during 12 weeks of instruction between mid-January and the end of April by teacher ranged from 11.49 hours to 17.43 hours, averaging 1.0 to 1.5 hours per week. Teachers' ratings of exposure were consistently higher than the actual exposure recorded by online statistics. Student absenteeism contributed to these differences; teachers estimated the amount of class time that they planned for students to work online; however, when students were absent they missed some of that allotted time causing their actual exposure time to be reduced. This is a plausible explanation because data from the attendance office revealed that among the 67 intervention students who took both administrations of the DA test, 22 of them (33%) were excessively absent, a classification they received by being absent 10 or more days in the school year.

A one-way ANOVA was conducted to determine if students' actual exposure time, according to online Apangea Math statistics, differed significantly based on teacher. The results showed a significant difference in usage among the teachers, $F(3,71) = 7.19$, $p < .001$, partial $\eta^2 = .23$, power = .98, effect size = .48. The results of the Bonferroni post hoc test showed that the exposure time of Cameron's students ($M = 11.49$, $SD = .72$) was significantly lower than the exposure time of both Akira's students ($M = 15.43$, $SD = .82$) and Drew's students ($M = 17.43$, $SD = 1.37$).

Quality of program delivery. The quality of program delivery was dependent on the technology working smoothly and the ability of the teachers to integrate their knowledge of content, pedagogy, and technology (TPACK knowledge) to support student learning. Ratings for the technical portion of delivery were gathered from teachers' forms and the classroom observation spot-checks. The technical portion of delivery on the implementation and observation forms was rated using a scale of 1 (*many technical problems*) to 5 (*smooth delivery; no technical problems*). The means and standard deviation for the quality of the technical delivery ratings recorded by teachers and during classroom observations are shown on Table 16.

Table 16. *Means and Standard Deviation for Quality of Technical Delivery*

Quality of Technical Delivery Ratings (from 1 to 5)	Teachers' Weekly Forms		Classroom Observation Spot-Checks	
Teacher	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Akira	4.06	(.88)	3.50	(.71)
Bryce	3.44	(1.35)	5.00	(.00)
Cameron	4.53	(.44)	5.00	(.00)
Drew	2.95	(.90)	4.25	(1.50)
Total	3.72	(1.09)	4.40	(1.08)

The means for the teachers' ratings of quality of technical delivery ranged from 2.95 to 4.53. There was a significant difference among the different teachers' ratings $F(3,31) = 5.14, p < .01$, partial $\eta^2 = .332$, power = .89, effect size = .58. The results of

the Bonferroni post hoc test showed that the ratings for technical delivery for Cameron's classes ($M = 4.53$, $SD = .31$) was significantly higher than those of Bryce's classes ($M = 3.44$, $SD = .33$) and Drew's class ($M = 2.95$, $SD = .29$). The mean rating for technical delivery for Akira's classes ($M = 4.06$, $SD = .33$) was also significantly higher than that of Drew's class.

The classroom observation ratings for technical delivery ranged from 3.50 to 5.00. The means of Akira, Cameron, and Drew's ratings were not statistically significantly different from those of classroom observations; however, an independent t -test revealed that Bryce's ratings of quality of technical delivery ($M = 3.44$, $SD = 1.35$) were significantly lower than the ratings received during classroom observations ($M = 5.00$, $SD = .00$), $t(7) = -3.28$, $p < .05$. The overall means of all teachers' ratings for technical delivery was similar to that of all classroom observations. The mean of all teachers' ratings was 3.72 and the mean of all classroom observation ratings was 4.40, indicating that overall, the quality of technical delivery was between 3 (*few or easily fixed technical problems*) and 5 (*smooth delivery; no technical problems*).

In addition to the smooth operation of technology, the quality of program delivery also depended on teachers' TPACK knowledge. Therefore, a TPACK survey was administered to the intervention group teachers to measure their knowledge about teaching mathematics with technology (see Appendix F). Each item on the survey was scored from 1 (*strongly disagree*) to 5 (*strongly agree*), and an average score was computed for each of the seven constructs (Schmidt, et al., 2009a). See Table 17 for the four teachers' scores on the TPACK survey.

Table 17. *Teachers' TPACK Scores on a Scale of 1 to 5*

Teacher	TK	CK	PK	PCK	TCK	TPK	TPACK	Composite
Akira	4.71	5.00	4.57	5.00	5.00	4.80	4.80	4.84
Bryce	4.00	4.00	4.14	4.00	4.00	4.00	4.00	4.02
Cameron	4.86	5.00	4.43	5.00	4.00	4.40	4.60	4.61
Drew	3.43	4.67	3.71	4.00	4.00	3.80	3.80	3.92

The scores for all four teachers for all seven types of knowledge, technological knowledge (TK), content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK), ranged from 3 to 5, indicating that none of the teachers' self-rated scores were below the neutral value of 3 for any of the knowledge domains.

Participant responsiveness. The fourth component of fidelity of implementation, participant responsiveness, was examined in detail in the Student Engagement Findings section of this chapter. It was concluded that even though the student engagement surveys did not reflect any significant changes in students' attitudes towards learning mathematics after they had been exposed to Apangea Math for approximately 12 weeks, other sources of data regarding student engagement (i.e., observation forms and questionnaires) provided evidence that many of students were engaged and working when interacting with Apangea Math.

Teachers' roles. An analysis of the data collected from the teachers' weekly forms and the classroom observations revealed that, three of the four teachers were observed spending a large portion of class time providing whole-class instruction. One teacher, Bryce, spent a little less time than the other teachers on whole-class instruction and more time assisting students as they practiced mathematics lessons on paper independently. See Table 18 for the percent of time teachers spent in various roles.

Overall, teachers' estimates of the time they spent in whole-class instruction were lower than what was recorded during classroom observations. The most pronounced discrepancy between teachers' self-reported data and classroom observations was in the category "Monitor students working on Apangea." All four teachers estimated the time they spent monitoring students as they worked on Apangea Math to be higher than classroom observations showed. A simple explanation for this may be that teachers tended to count all of the time that they allotted for students to access Apangea Math as time when they were monitoring students on Apangea Math. However, classroom observations indicated that teachers often used the time when students were on Apangea Math to do other things such as work at their desks or provide one-on-one instruction.

In an effort to determine if implementing blended learning led to an increase in personalized instruction, specific questions on the anonymous questionnaires administered to teachers and students at the end of the intervention were examined. The first item on the teachers' questionnaire asked "How did the enactment of the blended learning curriculum including Apangea and face-to-face instruction affect the differentiation of instruction in your classes?" The three teachers who responded to this

Table 18. *Percent of Time Teachers Spent in Various Roles (self-reported and observed)*

Role		Akira	Bryce	Cameron	Drew	Total
Whole-class instruction	Self-reported	46%	22%	41%	34%	35%
	Observed	66%	36%	65%	43%	53%
One-on-one or small group instruction	Self-reported	6%	22%	12%	10%	13%
	Observed	9%	43%	15%	16%	21%
Monitor students doing group work	Self-reported	8%	21%	12%	10%	13%
	Observed	6%	4%	9%	6%	6%
Monitor students working on Apangea	Self-reported	31%	19%	31%	31%	28%
	Observed	9%	9%	4%	5%	7%
Trouble-shoot technical problems	Self-reported	1%	6%	1%	6%	4%
	Observed	1%	0%	0%	0%	0%
Discipline students	Self-reported	2%	6%	2%	11%	5%
	Observed	0%	0%	0%	5%	1%
Analyze reports	Self-reported	0%	4%	0%	0%	1%
	Observed	0%	0%	0%	10%	2%
Other (e.g., administer test, work at desk, emergency drill)	Self-reported	6%	0%	0%	0%	1%
	Observed	10%	8%	11%	15%	11%

multiple choice question each selected a different response; one indicating that differentiation increased, one said it did not change, and one reported that it decreased as a result of enacting a blended learning curriculum including Apangea Math and face-to-face instruction.

The first three items on the students' questionnaire explored the learning opportunities that Apangea Math provided for students. The students were asked to rate these statements on a scale of 1 (*strongly disagree*) to 5 (*strongly agree*):

1. Apangea helped me understand math that I had difficulty with in the past.
2. Apangea gave me practice doing math that my Algebra teacher taught in class.
3. Apangea taught me new math concepts that I had never seen before.

Sixty-two of the intervention group students completed the anonymous questionnaire. Eighty-two percent of those respondents agreed or strongly agreed that Apangea gave them practice doing math that their Algebra teacher had presented in class, 65% agreed that Apangea helped them understand math concepts that they had previously found difficult, and 50% agreed that Apangea taught them new math concepts that they had never seen before (see Figure 5). Students' responses revealed that the content that was delivered to them via Apangea lessons was individualized for each student based on demonstrated knowledge; therefore, the lessons presented sometimes focused on Pre-Algebra concepts, often times included Algebra 1 concepts, and occasionally addressed more advanced mathematical concepts. The program's artificial intelligence adapted lessons so that some students received additional instruction and practice in areas where needed, while others who showed mastery in the Algebra lessons were directed toward

more advanced concepts. In this way, Apangea Math provided remediation as well as enrichment depending on students' achievement.

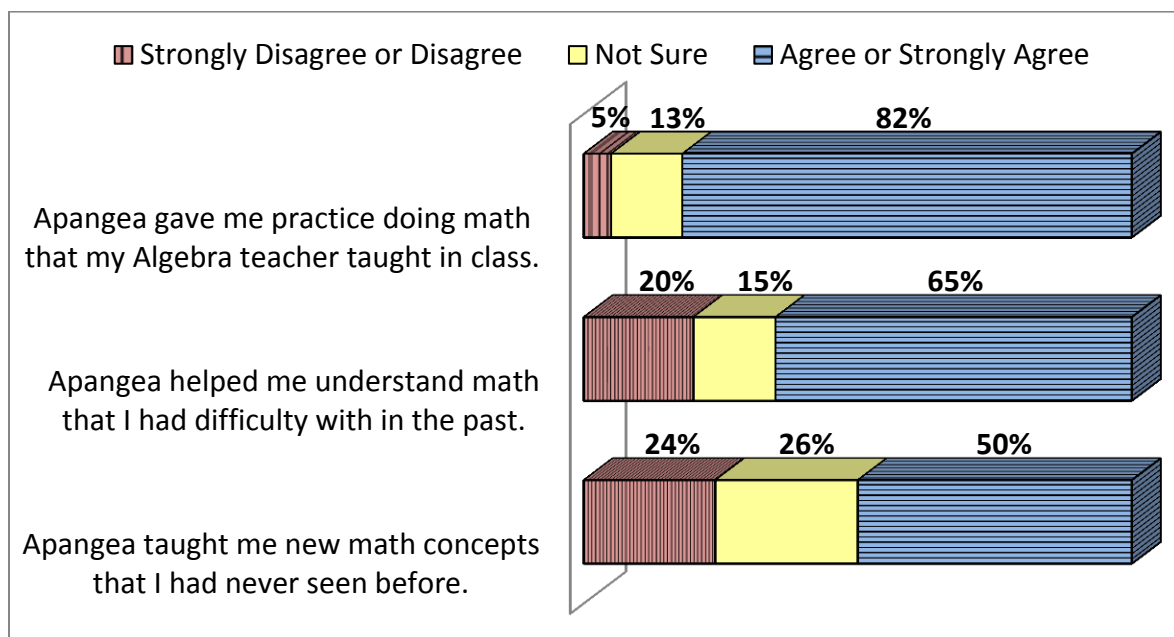


Figure 5. Students' responses about Apangea's contribution to their learning.

Challenges encountered and practices used. The qualitative data gathered from teachers' weekly forms, classroom observations, and meeting notes identified several challenges encountered during the implementation of Apangea Math as well as practices used to support learning. The data were entered into QDA Miner where each segment was categorized using open-style coding, which led to the identification of themes or patterns. For example, some of the codes used for challenges encountered were "network issues," "lack of time," and "disbelief in program," and some of the codes for practices were "provide personal instruction," "establish protocols," and "developing TPACK." After coding all the segments of data, the codes were retrieved, reviewed, and

adjusted iteratively. Adjustments, such as merging, splitting, and renaming codes, were made to ensure that codes were used in a clear and consistent manner. Additionally, each code was categorized as first-order (external) or second-order (internal) according to the Snoeyink and Ertmer (2001) framework. The analysis of the data revealed eight challenges (four first-order and four second-order) and six practices (four first-order and two second-order).

First-order challenges. The external challenges included network issues, software limitations, limited adherence, and help abuse. “Network issues” were slow or unreliable internet connectivity. Such problems were prevalent in the early weeks of the implementation of the program but were resolved when better access points were acquired and placed directly in each classroom. “Software limitations” had to do with the actual structure of the mathematical problems presented by the Apangea Math program and its flexibility (or lack thereof) to accept some of the students’ answers. When the program asked students to build equations to solve word problems, occasionally it would only accept one form of the equation as correct. For example, on a Pythagorean Theorem problem, the program accepted the equation in the form $a^2 + b^2 = c^2$ but would not accept the other mathematically correct answers such as $c^2 = a^2 + b^2$ or $c = \sqrt{a^2 + b^2}$. This type of programming problem did not occur often, but teachers and students found it frustrating when it did happen. Teachers depended on technology support staff from the school district to deal with network issues, and Apangea Math support was available via live chat to assist with the navigation of software limitations.

The first-order challenges of “limited adherence” and “help abuse” were related to student behaviors. Part of adhering to the Apangea Math program included students listening on headphones and writing their work on paper. The code, “limited adherence,” was used to identify instances when students were observed resisting the use of these tools. Students were expected to wear headphones to hear the audio portion of the tutorial and to have the option of clicking to have problems read aloud. Students were expected to use paper and pencil to record their thinking and help them work out problems, but many did not. Numerous classroom observation notes included statements about some students not wearing headphones or not using paper and pencil. When students failed to use headphones or paper and pencil, they were not fully adhering to the program. The code, “help abuse,” was assigned to cases when teachers reported seeing students clicked through hints quickly to get through lessons. For example, Drew reported on an observation form, “Some students are grossly misusing/abusing the coach help button and subsequently live chat.” The program responded to excessive rapid clicking with pop-up messages suggesting that students slow down. When teachers clarified to students that their Apangea Math grades were based on passing lessons as opposed to simply completing lessons, most of them slowed down and took a little more time to read and think.

Second-order challenges. Examination of the data revealed the following four internal challenges: lack of time, disbelief in the program, off-task behavior, and student burn-out. The reason teachers claimed a “lack of time” to be a challenge or barrier to implementing the online tutorial was primarily the result of the ever-present pressure of

high-stakes tests. The school had failed to make adequate yearly progress in recent years and was under the state's close scrutiny to improve. The sense of urgency to prepare students to take the Algebra 1 EOC mandated that students spend as much time as possible on the content that was expected to be on the test. Cameron cited "difficult EOC content to teach, time frame for EOC, schedule changes, [and] inservice day" as challenges causing a lack of time.

The code, "disbelief in the program," identified occasions when teachers or students expressed doubt in the ability of the program to be beneficial. For example, at one point in the semester, Akira reported, "students don't think the program is teaching them," and she explained that students expressed disappointment about Apangea Math's lessons not aligning directly with the content being taught in the face-to-face portion of the class, which caused them to think the program wasn't teaching them what they needed to know. Bryce reported "[Apangea] time cutting into teaching" as a challenge when implementing the program, revealing a disbelief or mistrust in the program's potential to support students' learning.

The second-order challenge, "off-task behavior," was a classroom management issue about which teachers expressed anxiety. The teachers in this study were pleased that the wireless computer tablets had been configured in such a way that students could not access any website other than Apangea.com; however, teachers still expressed difficulty managing the students who were inclined to be off-task during online learning time. During times that were designated for students to work on Apangea Math, some students were observed avoiding Apangea lessons by doodling with the computer's draw

tools and other students would talk too much. The code, “student burn-out,” was applied to instances when teachers described students’ diminished enthusiasm towards doing Apangea lessons, which happened after the novelty of using the new wireless tablet computers had worn off. Cameron reported, “kids getting burnt out and decrease desire to use program” and these concerns were discussed at a meeting.

First-order practices. Analysis of qualitative data identified the following four external practices as beneficial: establish protocols, provide incentives, provide personal instruction, and create learning pathways. The most frequently mentioned first-order practice was “establishing protocols.” Some of the protocols that were described as beneficial were scheduling online learning as a routine part of class time consistently and establishing expectations about the use of headphones and paper. In reference to requiring students to write out their work, Akira said, “Students have to take notes during the lesson portion,” Drew stated, “Have students use paper to map out [work],” and Cameron suggested “letting students use dry erase boards.” Classroom observations noted that “Those with headphones were more engaged in the program.” The details of integrating online learning into the daily schedule varied among teachers. Some started classes with Apangea Math, some ended their classes with it, and others did the program for longer sessions for fewer days per week. However, teachers agreed that commitment to the program and consistency was important.

The practice of “providing incentives” was enacted via assigning Apangea Math grades, rewarding top performing classes in a weekly grade level contest, and awarding points online in the Apangea program. Students earned weekly grades for Apangea

lessons passed. Within the Apangea Math program a score of 60% on a lesson was counted as passing; but because the Algebra 1 teachers considered 85 as proficient, the lessons passed in Apangea were curved accordingly. A formula was developed to compute the curved grades such that 60 was curved to be 85, 70 curved to 89, 80 curved to 93, 90 curved to 96, and 100 was equal to 100. Weekly Apangea Math grades also took into account the number of lessons passed by rewarding students with an increase of two points for each lesson they passed in excess of the expected four lessons and decreasing the weekly grade by two points for each lesson short of the expected four. Note that lessons completed but not passed were not figured into the formula at all because the Apangea program required students to retake those lessons. Drew said, “Explain[ing] how the grading system works” and “showing them their Apangea grade and its effect on their overall grade” were beneficial practices. Akira recommended, “implementing a leader board” as an incentive.

A grade-level contest established among the freshmen that recognized the three classes with the highest average number of lessons passed per student weekly provided another incentive. The winning classes were announced on Thursday mornings, hallway posters and decorations honored them, and the teachers of the winning classes got mints to share among their students. The Apangea program also provided an incentive by awarding online points to students based on their progress within the program; however the point levels required for redemption for T-shirts or gift-cards was so high that very few students ever attained those goals.

The first-order practice code, “provide personal instruction,” was assigned to interaction when teachers provided one-on-one or small group instruction. In some cases teachers used Apangea Math time to pull-out students and provide them face-to-face tutoring while the rest of the class was working online; Cameron reported, “individual tutoring while class is on Apangea” as a positive practice. In other cases, teachers responded to students with personal assistance when they asked for help while working on the online lessons; Drew reported, “sitting down and helping students 1-on-1.”

The practice of “creating learning pathways” was a practice that brought Apangea Math lessons into closer alignment with face-to-face instruction. In this study, Apangea Math was used in its fully adaptive mode from mid-January until mid-March. As pressure mounted to ensure that students would be prepared for the EOC, learning pathways that were adaptive were created to align with the Algebra 1 course content, and they were put into practice from mid-March until the administration of the EOC at the beginning of May. Teachers reported that students were more engaged when the online program directly linked to what they were doing in class. Cameron reported, “Students are more engaged now that the program is directly linked to what we are doing in class now.” At a meeting, another teacher said, “The pathways are ten times better than the fully adaptive mode.”

Second-order practices. The internal practices that emerged from the data coding were “self-directed learning” and “developing TPACK.” When teachers encouraged students to take time to read the coach help and to work through online lessons independently, they were helping students become more self-directed learners. Teachers

described practices they used to support students' development of self-directed learning: Akira reported "Not helping and letting students work it out," and Drew "Encouraged them to actually READ the coach help." Towards the end of the semester, Cameron made a remark about "students now using 'class coach' better and more frequently." There was evidence that teachers were developing TPACK knowledge throughout the study. They expressed acceptance of the online tutorial technology when they discussed at meetings how some students who do not do well in the face-to-face environment engaged well with the online tutorial and other students progressed to advanced content with Apangea Math. Teachers explored the use of the technology as they worked through online lessons on their own and accessed the program's sample content and answer key which exposed them to the format of the online problems and solutions. Looking at the impact of the online program, Drew declared, "Apangea is the best differentiation tool we have available to us." Data that provided evidence of teachers' growing belief that the use of Apangea Math integrated into a blended learning curriculum enhanced the teaching and learning of mathematics was seen in teachers' responses to an item on their anonymous surveys; all of the teachers responded "yes" to the question, "Now that you know the features of Apangea, do you believe it can be used beneficially in the teaching and learning of Algebra 1 in the future?"

Correlations. A Pearson r correlation was conducted to determine how factors such as exposure time students spent on the Apangea Math program, the number of lessons students passed in Apangea Math, Student Engagement pre and post-survey scores, DA pre-test scores, DA gains made, and EOC scores were related to one another.

It was revealed that the pre and post-survey scores for student engagement were not significantly correlated with any of the other factors. However, there were significant correlations among the factors, DA pre-test, Apangea time, Apangea lessons passed, DA gains, and EOC scores (see Table 19).

Table 19. *Correlations among Study Variables*

	DA Pre-tests	Apangea Time	Apangea Lessons Passed	DA Gains	EOC Scores
DA Pre-tests	_____				
Apangea Time	-.019	_____			
Apangea Lessons Passed	.416**	.587**	_____		
DA Gains	-.290*	.139	.358**	_____	
EOC Scores	.571**	.300**	.598**	.322**	_____

** $p < 0.01$ level.

* $p < 0.05$ level.

- The scores on DA pre-tests were significantly positively correlated with Apangea lessons passed, $r(67) = .42$, $p < .001$, $r^2 = .18$ and EOC scores $r(66) = .57$, $p < .001$, $r^2 = .32$, but significantly negatively correlated with DA gains $r(67) = -.29$, $p < .05$, $r^2 = .08$.
- Time that students spent on Apangea Math was significantly positively correlated with Apangea lessons passed, $r(75) = .59$, $p < .001$, $r^2 = .35$, and EOC scores $r(74) = .30$, $p < .01$, $r^2 = .09$.

- The number of lessons that students passed on Apangea Math was significantly positively correlated with DA gains $r(67) = .36, p < .01, r^2 = .13$, and EOC scores, $r(74) = .60, p < .001, r^2 = .36$.
- Gains made on DA tests were significantly positively correlated with EOC scores, $r(66) = .32, p < .01, r^2 = .10$.

Examining DA gains. The significant positive correlation between Apangea time and the number of Apangea lessons passed suggested that increased exposure time contributed to an increase in the number of lessons passed. Additionally, the significant positive correlation between the number of Apangea lessons passed and DA gains provided evidence that an increase in lessons passed contributed to students' gains on DA tests. The correlation between Apangea time and DA gains was positive; though it was not significant, suggesting exposure time contributed less to gains on DA tests than the number of Apangea lessons passed.

The significant negative correlation between DA pre-test and DA gains suggested that the higher students scored on the DA pre-test, the less they gained from pre to post DA test. This was consistent with a finding, described earlier in this chapter, which showed achievement gains were highest among the students whose initial DA skill level was below basic. To explore this phenomenon further, the means for the correlated variables were calculated based on initial DA skill level (see Table 20).

An ANOVA was conducted on intervention group students' data to determine if the correlated variables differed significantly based on students' initial DA skill levels.

Table 20. *Means of Correlated Variables by initial DA skill level*

	Below Basic	Basic	Proficient	Advanced
DA Pre-test	20.50	36.12	48.50	67.00
Apangea Time (hours)	15.31	14.80	13.00	15.65
Apangea Lessons Passed	17.88	21.27	27.38	32.63
DA Gains	24.50	7.46	7.46	5.25
EOC Scores	77.63	80.04	87.42	94.38

Initial DA skill levels were determined by DA pre-test scores; thus, as expected, DA pre-test scores differed significantly based on initial DA skill level, $F(3,62) = 155.93$, $p < .001$. Furthermore, a Bonferroni post hoc analysis showed that the mean DA pre-test score for each initial DA skill level was significantly different from the mean DA pre-test score for every other initial DA skill level. These initial DA skill levels represent a measure of students' aptitude.

The mean amount of time that students spent on Apangea during the semester based on initial DA skill level ranged from 13.00 hours to 15.65. Apangea time did not differ significantly based on initial DA skill level, $F(3,62) = 1.53$, $p = .215$. The mean number of Apangea lessons passed per student based on initial DA skill level ranged from 17.88 to 32.63. Even though there appeared to be a consistent trend indicating that as students' initial DA skill level went up, the number of Apangea lessons they passed increased, the ANOVA results showed Apangea lessons passed did not differ significantly based on initial DA skill level, $F(3,62) = 2.30$, $p = .087$. Thus, these aspects

of the treatment (Apangea time and Apangea lessons passed) did not differ significantly based on initial DA skill level.

However, DA gain, an outcome variable in this study, differed significantly by initial DA skill level, $F(3,62) = 5.11, p < .01$. The Bonferroni post hoc test showed that the students who had an initial DA skill level of below basic had statistically greater DA gains ($M = 24.50, SD = 11.46$) than those with initial DA skill levels of basic ($M = 7.46, SD = 13.67$), proficient ($M = 7.46, SD = 9.74$) and advanced ($M = 5.25, SD = 11.41$).

These analyses of the relationships between students' aptitudes (initial DA skill levels), the treatment variables (Apangea time and Apangea lessons passed), and the outcome variable (DA gain) revealed that the treatments' effects on students' achievement gains differed significantly based on their aptitude, constituting an aptitude-treatment interaction. Instruction that included the use of the ITS, Apangea Math, significantly improved achievement for students whose initial DA skill level was below basic but did not change achievement significantly for those whose initial DA skill levels were higher (basic, proficient, or advanced).

Predicting EOC scores. A standard multiple regression was conducted to determine the best prediction equation that could be created to predict EOC scores. Initially, the predictor variables, DA pre-test scores, Apangea time, Apangea lessons passed, and DA gains, were included; however, there were multicollinearity problems. The predictor variable, Apangea lessons passed, was highly intercorrelated with Apangea time and DA pre-test scores. To alleviate this problem, a combined/average of the two variables, Apangea lessons passed and Apangea time, was computed as a new variable

called *Apangea combined*. The combination of these two variables made conceptual sense because they were related treatment variables, and as show in Table 19, they were highly related ($r = .59$). Table 21 displays the means, standard deviations, and intercorrelations for these variables, showing that all of these variables were significantly correlated.

Table 21. *Means, Standard Deviations, and Intercorrelations for EOC Scores and Predictor Variables (N = 66)*

Variable	<i>M</i>	<i>SD</i>	DA pre-test	Apangea combined	DA gains
EOC Scores	84.17	(9.60)	.57**	.53**	.32**
Predictor Variables					
DA Pre-test	42.47	(13.59)	—	.35**	-.30**
Apangea Combined	14.31	(3.94)		—	.34**
DA Gains	9.26	(12.91)			—

* $p < .05$; ** $p < .01$

A standard regression was run with the three predictor variables, DA pre-test, Apangea combined, and DA gains. This combination of variables (DA pre-test, Apangea combined, and DA gains) significantly predicted EOC scores, $F(3,62) = 31.30$, $p < .001$, $R = .78$ and $\text{Adj. } R^2 = .58$. The adjusted R^2 value indicated that 58% of the variance in EOC scores was explained by this model, which is a large effect. DA pre-test scores ($\beta = .67$, $\text{sr}_1^2 = .30$), and DA gains ($\beta = .48$, $\text{sr}_1^2 = .16$) were significant predictors.

The beta weights suggested that DA pre-test scores contributed the most to predicting EOC scores, and DA gains and the Apangea combined variable also contributed positively (see Table 22).

The prediction equation for Y, the EOC score, for intervention group students was

$$Y = 58.01 + .472(X_1) + .146(X_2) + .354(X_3) + e$$

where X_1 = DA pre-test score, X_2 = Apangea combined, X_3 = DA gains, and e = error.

Table 22. *Standard Multiple Regression Analysis for DA Pre-test, Apangea Combined, and DAGain, Predicting EOC Scores (N = 66)*

Variable	<i>B</i>	<i>SE</i>	β
DA Pre-test	.47	(.07)	.67**
Apangea Combined	.15	(.11)	.13
DA Gain	.35	(.07)	.48**
Constant	58.01	(2.87)	

Note. $R^2 = .60$; $F(3,62) = 31.30$, $p < .001$

* $p < .05$; ** $p < .01$

Examining correlated factors by teacher. In the complex environment of classroom settings, implementation conditions naturally vary based on teachers' instructional decisions. Table 23 displays the means of the correlated factors (Apangea time, Apangea lessons passed, DA pre-test, DA gains, and EOC scores) by teacher.

Drew's students spent the most time on Apangea (17.45 hours) followed by Akira's students (15.43 hours) and then Bryce's students (13.06 hours). Cameron's

Table 23. *Means of Correlated Factors by Teacher*

	Akira	Bryce	Cameron	Drew
DA Pre-test	38.29	56.54	42.00	32.63
Apangea Time (hours)	15.43	13.06	11.49	17.43
Apangea Lessons Passed	21.77	26.13	19.66	31.50
DA Gains	10.48	6.00	8.80	14.37
EOC Scores	82.23	88.06	80.79	79.50

students had the least amount of exposure to Apangea (11.49 hours). Pearson correlation tests showed that time on Apangea was correlated with the number of Apangea Math lessons passed; therefore, it was reasonable that the average number of lessons passed per student by teacher was highest for Drew's students (31.50 lessons) and lowest for Cameron's students (19.66 lessons). Drew's students also achieved the greatest gains (14.37 points) from pre to post DA test. Akira's students, who had the second highest amount of exposure, had the second highest DA gains (10.48 points). The high DA gains earned by Drew's and Akira's students are most likely also related to the fact that Drew's and Akira's students had lower DA pre-test scores than the other two classes. As shown previously, the intervention group students with initial DA skill level of below basic (as determined by DA pre-tests) made significantly greater gains than students who started the course at higher skill levels.

Summary of Results

Student achievement in mathematics increased in the classrooms using blended learning. More students in the intervention classrooms scored higher on the summative EOC exam, and analysis of achievement gains made on the formative DA tests revealed that the intervention group's mean gain of 9.54 points was significantly greater than the comparison group's mean gain of 4.65 points. However, gains were not seen consistently across all of the content standards. The only content area in which the intervention group did not make greater gains than the comparison group was Mathematical Processes. Achievement gains for intervention group students were seen to varying degrees for students with different aptitudes. Among students with initial DA skill levels of below basic, the intervention group attained significantly greater gains than comparison group; whereas, among students with higher initial DA skill levels, the intervention and comparison groups' gains were not significantly different.

The fidelity of implementation of Apangea Math was evaluated on four components: adherence, exposure, quality of delivery, and participant responsiveness. Adherence measured how well the implementation adhered to program design. Teachers' ratings for adherence did not differ significantly by teacher, but they were consistently a little higher than classroom observation ratings. Teachers also tended to overestimate the amount of time that students were exposed to Apangea Math, though excessive student absenteeism may have contributed to the discrepancy between teachers' estimates of allotted time for Apangea Math and online statistics regarding students' actual usage time. The means for students' actual exposure time per week differed significantly by

teacher. For technical delivery, three of the teachers' ratings were similar to their classroom observations' ratings; however, Bryce rated technical delivery significantly lower than observations. For participant responsiveness, teachers' ratings did not differ significantly from each other; however Akira rated responsiveness significantly higher than observations, and Drew rated it significantly lower than observations.

Overall, teachers spent a large portion of class time providing whole-class instruction, though their estimates of the time they spent in whole-class instruction tended to be lower than that reported in classroom observations. They also tended to estimate more time spent monitoring students working on Apangea Math than was documented by observations. It was apparent that teachers tended to count the entire allotted time for the Apangea Math program as time spent monitoring students on-line; whereas, observations noted that teachers often used the time when students were on-line to do other things such as work at their desks or provide one-on-one instruction.

Pearson r correlations revealed that Apangea exposure time was significantly positively correlated with the number of Apangea lessons passed, and the number of Apangea lessons passed was significantly positively correlated with gains made on DA tests. DA pre-test scores, Apangea exposure time, Apangea lessons passed, and gains on DA tests were all significantly positively correlated with EOC scores. Though many questions about implementation of the program remain, it is clear that implementing the blended learning program contributed to improved student achievement for ninth grade Algebra 1 students in this urban high school.

Chapter 5

Conclusions

The purpose of this dissertation was to determine the effects of the ITS program, Apangea Math, on students' engagement and achievement in Algebra 1. Furthermore, the intent of this study was to examine the fidelity with which Apangea Math was implemented and reveal the challenges encountered and teaching practices used. Student achievement was determined using scores on summative Algebra 1 EOC exams and formative DA tests. Student engagement was evaluated based on student perceptions that were revealed through surveys and questionnaires; teachers' perceptions expressed via forms, meetings, and questionnaires; and my own observations.

The implementation of the program was documented from the standpoint of teachers who completed weekly Implementation and Observation forms, a TPACK survey, and a questionnaire; from the standpoint of students who completed a questionnaire; and from my standpoint as the researcher as I completed forms, gathered online statistics, and recorded meeting notes and observations. This final chapter presents confirmed findings and lessons learned, discusses implications for teachers and administrators, and suggests recommendations for future research.

Confirmed Findings

Achievement gains depended on initial student aptitude. Prior to taking a formal Algebra course, students must understand many foundational mathematics concepts that are considered prerequisites to learning Algebra (G. Brown & Quinn, 2006, 2007; Capraro & Joffrion, 2006; Carpenter, et al., 2003; Ding & Li, 2010; Ellis, 2011;

Herbert & Brown, 1997; Loveless & Coughlan, 2004; Matthews, et al., 2012; Tent, 2006; Wu, 2001). Students who lack adequate preparation tend to do poorly in regular Algebra 1 classes because they need additional support to learn the prerequisite skills (Stein, et al., 2011). Based on the fact that the high school in this study had failed to make adequate yearly progress in mathematics in recent years, it was apparent that the students needed additional support to become successful in Algebra 1.

In the literature review, instructional technology was described as having the potential to provide needed support for students (Ellington, 2003; Guerrero, et al., 2004; Harmon, 2011; Huffmyer, 2008; Mo, 2011; Scherer, 2002). This study further supported that claim by providing empirical evidence that implementing a blended learning model of education, which integrated an ITS program, Apangea Math, with face-to-face instruction, resulted in significantly improved student achievement in Algebra 1 in this urban high school. On the EOC exam, the intervention group students ($M = 82.65$, $SD = 10.95$) scored significantly higher than comparison group students ($M = 71.21$, $SD = 14.45$), $t(170.96) = 5.92$, $p < .001$, $d = .88$. On the DA tests, there was a significant interaction effect between time (pre or post) and group (intervention or comparison), $F(1,157) = 5.25$, $p < .05$, partial $\eta^2 = .032$, indicating the intervention group's gains were significantly greater than the comparison group's gains.

Additional analyses revealed that the intervention and comparison group students' outcomes differed based on their initial aptitude, which was measured by DA pre-tests and categorized into DA skill levels. Among the students who initially scored at the below basic skill level, the intervention group made significantly greater gains than the

comparison group; whereas, gains made by students at the higher skill levels did not differ significantly by treatment group. This indicated that there was an aptitude-treatment interaction, meaning the effect of the intervention treatment differed based on students' aptitude. Among the students whose initial DA skill level (aptitude) was below basic, the change-over-time for the intervention group from pre-test ($M = 20.50$, $SD = 3.59$) to post-test ($M = 45.00$, $SD = 11.16$) was significantly greater than the comparison group's change from pre-test ($M = 22.78$, $SD = 5.18$) to post-test ($M = 33.69$, $SD = 10.59$). See Figure 6 for a pictorial representation of the change in achievement over time by treatment group for students whose initial DA skill level was below basic.

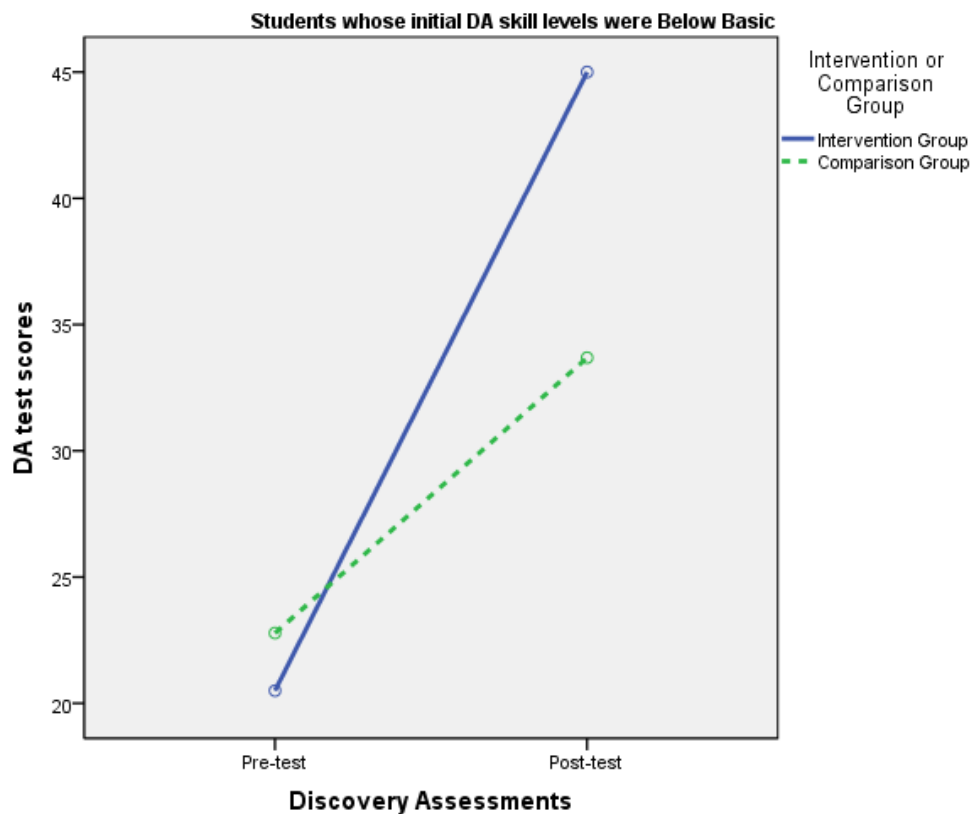


Figure 6. DA gains among students with below basic aptitude by treatment group.

This indicated that among students who started at the below basic skill level, intervention group students' gains ($M = 24.50$) were significantly greater than the comparison group's gains ($M = 10.91$), $F(1,38) = 9.93$, $p < .01$, partial $\eta^2 = .21$. Thus, instruction that included the use of Apangea Math improved achievement for students whose initial DA skill level was below basic significantly more than instruction that did not use Apangea Math.

In the context of this study, in an urban school, which had been failing to make adequate yearly progress, the achievement data showed that implementing the blended learning program with Apangea Math contributed to increased student achievement. However, correlations among study variables for the intervention group revealed a negative correlation between their DA pre-test scores and their DA gains, indicating that as intervention students' DA pre-test scores went up, their DA gains went down. Therefore, additional analyses were conducted on sub-groups of students based on their initial DA skill levels. The results indicated that for the intervention group students, those whose initial DA skill level was below basic showed significantly greater gains than those who started at higher skill levels. Thus, it can be concluded that including the use of the ITS, Apangea Math, significantly improved achievement for students whose initial DA skill level was below basic, but it did not change achievement significantly for those whose initial DA skill levels were higher.

Based on these analyses, administrators and educators should take into account the initial skill levels of their students when considering whether or not to implement a blended learning program like the one in this study. The capital investment in hardware

and software would be worthwhile for students whose initial skill levels are low (below basic) because the achievement gains made by low aptitude students were significantly improved when they received the intervention. The personalized online lessons that were provided by Apangea Math provided support for students with low initial DA skill levels to learn the prerequisite skills needed for success in Algebra 1. The capital investment in the intervention may not be worthwhile for students whose initial skill levels are higher (basic, proficient, or advanced) because the achievement gains made by higher aptitude students were not significantly greater when they received the intervention.

Student engagement survey results were inconclusive. In the literature, well-designed computer programs were said to prompt students to engage and interact in meaningful learning activities (Chen, et al., 2011; Mupinga, 2005). Furthermore, ITS programs, which utilized artificial intelligence to adapt lessons, were credited with the ability to ensure that there is an appropriate balance between the challenge of tasks and students' skills (Corbett, et al., 1997; Fleisher, 2006; Huffmyer, 2008; D. L. Johnson, 2005; Koedinger, et al., 1997); therefore, ITS programs were touted to promote student engagement by supporting learning *flow* (Scherer, 2002). Thus, in this study, it was anticipated that Apangea Math would improve student engagement.

In prior research, student engagement was measured in different ways: survey responses (Harmon, 2011; Kuh, et al., 2006; McClure, 2006; Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003b), achievement scores (Harmon, 2011; McClure, 2006), and time working online (Mo, 2011). In this study, when student engagement data was gathered from student surveys, teachers' ratings, observations, and questionnaires, the

effect of the program on student engagement remained inconclusive. Analysis of students' responses to pre and post-surveys revealed no significant changes from the beginning to the end of the intervention. Analysis of teachers' ratings, observations, and questionnaires indicated that student engagement was present at a level that was little more than moderate. However, if student achievement gains were interpreted as a measure of student engagement in this study as they have been in other studies (Harmon, 2011; McClure, 2006), then the achievement gains made by the intervention group, which were significantly greater than that of the comparison group, would be interpreted as evidence of increased student engagement.

Lessons Learned

In this study, examination of the data revealed some interesting facts, anomalies, and patterns that warrant additional discussion. Because this research took place in the complex environment of natural classrooms, isolating the effects of the intervention from other possible influences was very challenging (A. L. Brown, 1992). Likewise, determining the specific causes for particular results was impossible (Gravetter & Wallnau, 2011); thus, rather than inferring causation, influential factors were viewed as contributing factors. Lessons were learned and some speculation arose from considering possible factors that may have contributed to or explained the following results in this study.

Achievement decreased in Mathematical Processes. The effect of the blended learning program on achievement was not positive in all of the Algebra 1 content

standards. Intervention group students' DA scores improved in all but one of the TN mathematics content standards; their scores decreased in the content standard of Mathematical Processes. This unexpected outcome suggested that the blended learning program was ineffective at developing students' understanding in this particular content standard. Mathematical Processes included identifying slope in multiple contexts, understanding equations for contextual problems, using an equation in context, applying properties, and translating representations of functions; in other words, understanding the connections between real world word problems, their mathematical equations, and their graphs.

One factor that may have contributed to the evident ineffectiveness of the blended learning program to support student learning in the content standard of Mathematical Processes was software limitations; in particular, Apangea Math occasionally failed to recognize all possible mathematically correct forms of equations. When this occurred, some of the students' mathematically correct representations of word problems were not accepted when their equations were formatted in ways not recognized by the program. Teachers said this challenge caused frustration for some students; thus, they may not have persevered or benefitted from the lessons in Apangea that required them to translate word problems into mathematical equations.

Another explanation for students' lack of learning in the content standard, Mathematical Processes, could be a decrease in the amount of face-to-face instruction. Face-to-face instructional time was reduced during the intervention period because a portion of class time was dedicated to students working online in the Apangea Math

program. Additionally, teachers' choices regarding the role they played while students worked online could have contributed to students' lack of progress in the Mathematical Processes content standard. Occasionally, some teachers chose to spend students' online time working at their desks when they could have been coaching students through the contextual problems and encouraging them to persevere in formulating equations. Teachers' may have missed opportunities to facilitate student learning by not monitoring their online learning time more closely.

Student engagement was elusive. The analysis of pre and post student engagement surveys revealed no significant change in students' self-reported attitudes toward learning mathematics. One possible explanation for this lack of change-over-time could be that students may not have responded honestly to survey items. As explained in Chapter 1, the student engagement survey data was limited to students' self-perceptions and it was assumed that students would express those perceptions honestly. However, students may have selected responses that they perceived as appropriate rather than providing their honest opinions. Another possible explanation for the inconclusive outcome from the student engagement surveys could be the intervention time was too short. Twelve weeks may not have been an adequate amount of time to significantly alter the attitudes that students have developed towards learning math over many years. Perhaps, a longitudinal study would reveal if student engagement is effected by blended learning.

Teachers' perceptions versus observations. Teachers' perceptions sometimes did not match other measures of implementation. Teachers' ratings of the

components of fidelity of implementation (i.e., adherence, exposure, quality of delivery, and participant responsiveness) occasionally differed from other measures of the same components. Teachers' ratings of adherence, the first component of fidelity of implementation, were consistently a little higher than classroom observation ratings for adherence, which was anticipated based on the literature (O'Donnell, 2008) which stated that it is not uncommon for self-reported data of fidelity to be higher than data from field observations. A possible explanation for teachers' overestimation of their ratings for adherence could have been they made minor adaptations that were viewed during observations as a lack of fidelity (Lendrum & Humphrey, 2012); for example, teachers permitted students to use online calculators instead of the classroom calculators because they either did not fully understand the protocols for adherence or they felt it was an acceptable change. An alternate explanation for the incongruent measurement of adherence could be the subjective nature of measuring adherence (Lendrum & Humphrey, 2012).

Teachers also tended to overestimate students' exposure to Apangea Math compared to online statistics reports of program usage. Excessive student absenteeism (33% of the students were absent 10 or more days) may explain why teachers' estimates of students' exposure time to be higher than their actual time; teachers may have estimated the time allotted for Apangea, without considering time that students missed. Otherwise, the discrepancies between teachers' estimates and reality may have been caused by teachers' inaccurate perception or their desire to appear compliant.

For technical delivery, an aspect of quality of delivery, the third component of fidelity of implementation, only one teacher's mean rating differed significantly from that of classroom observations; Bryce's rating of technical delivery was significantly lower than that of classroom observations. This disconnect between Bryce's self-ratings and classroom observations regarding quality of technical delivery may be an example of a first-order challenge concealing a second-order challenge (Snoeyink & Ertmer, 2001). Specifically, on multiple occasions, Bryce made remarks about how he felt Apangea Math was cutting into teaching time, which revealed his disbelief in the program's potential to support learning (a second-order challenge). This lack of confidence in the program may have contributed to his over-reporting of technical issues (a first-order challenge). Inflating technical issues may have been an attempt to mask his disbelief in the program.

For the fourth component of fidelity of implementation, participant responsiveness, teachers' ratings did not differ significantly from each other. However, Akira's mean rating was significantly higher than what classroom observations reported, and Drew's mean rating was significantly lower than classroom observations reports. These discrepancies between teachers' ratings and observations may be the result of the subjective nature of rating this component of fidelity (Lendrum & Humphrey, 2012). Furthermore, these two teachers' expectations for student behavior and responsiveness may differ substantially from that of the observer. Akira's expectations for student responsiveness may be considerably lower than the observer's, and Drew's expectation may exceed the observer's expectations.

Fidelity affected achievement. Increased levels of fidelity of implementation contribute to increased achievement (E. Johnson, et al., 2006; Lendrum & Humphrey, 2012; O'Donnell, 2008; Protheroe, 2008). The influence of fidelity of implementation to impact student outcomes was evident in this study when examining gains made by the students of the two teachers who taught Algebra 1 during both the intervention and the comparison periods. Implementation of the intervention led to significantly greater gains for the students of one of the teachers but not the other. For Akira, the gain in intervention group's achievement scores ($M = 10.48$, $SD = 12.28$) was significantly greater than that of the comparison group ($M = 0.52$, $SD = 13.42$); but for Bryce, intervention group's scores ($M = 6.00$, $SD = 10.08$) were not significantly different from the comparison group's scores ($M = 5.00$, $SD = 12.75$). Based on the data collected in this study, a pattern emerged showing Akira's ratings for the components of fidelity of implementation were higher than Bryce's ratings. For adherence, Akira's mean rating was 4.41 while Bryce's was 3.88. For exposure, Akira's mean estimate was a rating of 3.56 while Bryce's was 3.31, and online statistics indicated that the actual average exposure time per student during the intervention period was 15.43 hours for Akira's students and 13.06 hours for Bryce's. For TPACK knowledge, a part of the component of quality of delivery, Akira's composite score was 4.84 while Bryce's score was 4.02. For technical delivery, another part of the component of quality of delivery, Akira's average rating was 4.06 while Bryce's was 3.44. For participant responsiveness, Akira's mean rating was 4.21 while Bryce's was 4.00. Overall, the higher fidelity with which

Akira implemented the program can be viewed as contributing to the greater gains made by Akira's students.

Closing achievement gaps. Even though DA pre-test scores were the largest contributing factor in predicting EOC scores, the Apangea Math program and DA gains helped close achievement gaps. Pearson correlations revealed that Apangea time and the number of Apangea lessons passed were positively correlated with DA gains (see Table 19). However, a close examination of correlated factors by initial DA skill level (see Table 20) and by teacher (see Table 23) revealed that the weight of the contribution of initial achievement levels (measured by DA pre-tests) led to EOC scores that tended to parallel DA pre-tests more than DA gains. This was seen clearly when outcomes for Drew's students were examined. Drew's students' spent the longest amount of time on Apangea, passed the most Apangea lessons, and made the greatest gains from pre to post DA test; nevertheless, Drew's students had the lowest DA pre-test scores which contributed greatly to them earning the lowest EOC scores. The pattern of EOC scores paralleling DA pre-tests more than DA gains was also evident when looking at the data for Bryce's students. When comparing outcomes by teacher, Bryce's students showed the lowest gains on DA tests, but they had the highest DA pre-test scores and the highest EOC scores.

The prediction equation for EOC scores for the intervention group students also reflected this pattern of previous knowledge explaining more of the variance in EOC scores than other factors: $Y = 58.01 + .472(X_1) + .146(X_2) + .354(X_3) + e$ where Y = EOC score, X_1 = DA pre-test score, X_2 = Apangea combined variable, and X_3 = DA

gains, and e = error. This equation showed that for each point higher a student scored on the DA pre-test, they were predicted to score about a half of a point (.472) higher on the EOC. For each point higher on the combined Apangea variable (average of Apangea time and Apangea lessons passed), they were predicted to score about a seventh of a point (.146) higher on the EOC. For every point a student's DA gain from pre to post-test went up, they were predicted to score about a third of a point (.354) higher on the EOC.

Even though the influence of DA pre-test scores was the greatest contributing factor to EOC scores, the contribution of Apangea variables and DA gains was apparent when comparing correlated factors by initial DA skill level (see Table 20) and by teacher (see Table 23). Examination of pre-test scores by teacher showed there were considerable achievement gaps between the students by teacher; Drew's students' DA pre-test scores (32.63) were 14.8% lower than those of Akira's students (38.29), 22.3% lower than Cameron's students (42.00), and 42.3% lower than Bryce's students (56.54). However, for EOC scores, Drew's students' scores (79.50) were only 3.3% lower than Akira's students (82.23), only 1.6% lower than Cameron's students (80.79), and only 9.7% lower than Bryce's students (88.06). The aptitude-interaction effect was in Drew's students' favor since they had the lowest mean DA pre-test score. They spent more time on Apangea, passed more Apangea lessons, and made greater gains on DA tests than any of the other teachers' students, which contributed to the reduction of their achievement gaps.

Considerations for Administrators and Teachers

Planning for the implementation of a new blended learning program necessarily requires teachers and administrators to consider and coordinate multiple factors; namely, technological requirements, training and support, establishing protocols, and evaluating results. The importance of these factors is discussed below in order to provide practical information for educators who may be considering implementing similar programs.

Technology Requirements. Devaney (2012) recommended internet connectivity be able to support many students accessing the network simultaneously in order to avoid network crashes. During the implementation of the program in this study, accessing the network was initially a problem. The large number of wireless tablet computers attempting to access the internet simultaneously caused connectivity problems. Network resources were too low for some students to login, and those who were able to login experienced web pages loading too slowly. Within the first week, the school system's technology personnel determined that there were too few wireless access points, and since they were mounted on the ceiling in the hallway, they were located too far away from the students in the classrooms. They remedied the problem by providing each classroom with its own dedicated wireless access point.

According to the literature, some mathematics teachers have been reluctant to use technology because they feared it would fail during instruction and response times from technical support would be slow (Wachira & Keengwe, 2011). Butler (2010) credited easy access to technical support for helping teachers and students develop trust in new technology based programs. The teachers in this study received prompt ongoing

technical support in-person from the high school's full-time instructional technology coordinator, and remotely via live online chat with classroom coaches through the Apangea website.

My observations in classrooms and discussions at meetings revealed that teachers were initially skeptical about the delivery of the Apangea Math program because of the network connectivity issues. However, the prompt resolution to those problems combined with the close attention of the instructional technology coordinator quelled teachers' complaints and concerns about the viability of the technology. Clearly, it is essential for administrators to ensure that technology requirements are addressed prior to the start of any new online program; otherwise, they risk damaging teachers' enthusiasm for the implementation of the programs.

Communication. Even though communication between administrators and teachers about new instructional technology is advisable (Devaney, 2012), teachers have reported being left out of the decision making process concerning technology needs in their schools (Wachira & Keengwe, 2011). This was the case in this study; administrators determined what hardware and software would be purchased without securing teachers' buy-in, and teachers' annoyance about this was expressed during an initial contact meeting. Thus, literature and evidence from this study both suggest that administrators who are contemplating new technology purchases would be well advised to communicate with everyone who will be involved in the implementation of the new technology and include them in the decisions about what to purchase.

The literature further recommended, when beginning to teach with a new online program, that implementation be mandated with expectations well defined (Butler, 2010). In this study, a large portion of school improvement grant funds were invested in the hardware and software needed for the Apangea Math program, and administrators clearly mandated that all the ninth-grade, regular education, Algebra 1 teachers implement the program. Subsequently, I met with these teachers prior to the start of the program in order to establish expectations regarding exposure time, adherence details, and grading practices. Because teachers had reported being left out of the decision making process to purchase this program, it was important to allow them to express their ideas and opinions about the details of implementation protocols. While considering and discussing teachers' ideas about how to including students' Apangea work in their grade books, I observed that the teachers began to slowly take some ownership of the implementation process as they were given the opportunity to contribute to decisions that established some of the expectations for implementation.

Developing TPACK. The blended learning model of instruction was new to the teachers in this study; thus, the TPACK Development Model was a useful framework for examining what teachers experienced throughout the implementation of the program. This model helps explain how teachers become proficient at integrating TK with PCK by outlining five stages that teachers typically go through as they learn to effectively employ new instructional technology (Niess, et al., 2009). Learning that the administration was acquiring the wireless tablet computers and subscriptions to the Apangea Math program

represented the first stage of the TPACK development model for the teachers in this study; namely, *recognizing* the technology was available prior to using it in teaching.

In the second stage of the TPACK Development Model, *accepting*, teachers grow to accept that using the technology may be appropriate for teaching and learning (Niess, et al., 2009). It is important for teachers to be aware of the pedagogical affordances provided by instructional technology (Butler, 2010; Snoeyink & Ertmer, 2001), and for teachers to understand both how to use the new technology and why the new technology is expected to improve learning (Comas-Quinn, 2011). Teachers in this study were made aware of these things during PD sessions.

During a routine Wednesday afternoon PD session prior to the start of the program, a visiting representative from Apangea Learning conducted an initial orientation to the Apangea Math program showing teachers how to use the software and explaining why the program was expected to support student learning based on the pedagogical value of Apangea Math's adaptive mode, which individualized lessons to meet the needs of each student. During another PD session prior to the implementation of the program, the high school's instructional technology coordinator provided teachers a training about how to use of the wireless tablet computers.

Furthermore, as the Algebra 1 consultant, I provided ongoing PD during three or four Wednesday afternoons per month throughout the implementation of the program. During these meetings, we discussed the pedagogical affordances of the program, analyzed online Apangea data and student progress, and reflected on challenges in implementation and changes in practice. Clearly, as recommended in the literature

(Butler, 2010; Comas-Quinn, 2011; Snoeyink & Ertmer, 2001), the weekly PD schedule provided time for the teachers in this study to learn how to use the technology and why it was expected to support student learning.

In the third stage of the TPACK Development Model, *adapting*, teachers interact with the technology in preparation for its use in teaching (Niess, et al., 2009). Drew described an adaptive practice on a weekly Implementation and Observation Form that prepared teachers to assist students, saying that previewing content was “Helping them (and myself) figure out what Apangea is looking for.” In this study, the adapting stage was not restricted to the time prior to the implementation, but continued throughout the semester.

In the fourth stage, *exploring*, teachers actually integrate the technology into the teaching and learning of mathematics (Niess, et al., 2009). At the beginning of this study, Apangea Math was implemented in fully adaptive mode whereby students’ lessons were determined by their online placement test results. This led to students receiving lessons that effectively helped them fill learning gaps in mathematics, which is a good example of competency-based pathways that provide opportunities for students to learn at their own pace and experience incremental success (Patrick, 2011).

However, because some students were particularly low-achieving, the lessons may not have progressed to include the Algebra 1 curriculum content until late in the semester if at all. This caused teachers to worry that the Apangea Math program might not help these students learn the concepts that would be assessed on the high-stakes Algebra 1 EOC exam. Thus, teachers explored the feature in Apangea called “Learning

Pathways,” which gave administrators and teachers the ability to assign designated content. The learning pathways could be created to be adaptive or not. If the learning pathways were assigned in a non-adaptive mode, the ability of the program to personalize lessons would have been eliminated; thus, the advantage of having tasks match students’ skills would have been lost. Recognizing the desirability of allowing the program to adapt and personalize lessons, but also considering the time constraints imposed by the urgency to prepare students for high stakes tests, a compromise decision was made to assign ‘adaptive’ learning pathways. This setting in Apangea Math allowed teachers some control to designate what online content would be delivered to the students, and simultaneously enabled the program to adapt and deliver the precursor lessons required for success in those designated lessons as needed by each student. This proved to satisfy both the desire to let the program adapt to students’ skill levels and the need to deliver specific content. I viewed the flexibility afforded to teachers by the option to assign adaptive learning pathways to be a local modification that supported effective implementation in the given setting (Lendrum & Humphrey, 2012; Protheroe, 2008).

Assigning the students to adaptive learning pathways in Apangea was acknowledged by teachers as a practice that benefitted the implementation of the program. Akira credited the practice as positive when she stated that the content was then “connected to what we were learning in class.” Likewise, Cameron stated that “students were more engaged now that the program directly linked to what we are doing in class.” At the weekly meeting after the assignment of learning pathways, teachers

made comments indicating that they thought “the pathways were ten times better than the fully adaptive mode.”

The final stage in the TPACK Development Model, *advancing*, is the point when teachers evaluate the results of using the technology and integrate their TK with their PCK resulting in TPACK knowledge (Niess, et al., 2009). Meeting notes revealed that teachers said they will be able to use Apangea Math better next year now that they know how to use learning pathways. This sentiment was further verified when 100% of the teachers who responded to the anonymous questionnaire said yes to the question, “Now that you know the features of Apangea, do you believe it can be used beneficially in the teaching and learning of Algebra 1 in the future?”

Change. According to the literature, the primary pedagogical affordance provided by using an ITS in a blended learning environment was the personalization of instruction where students learn at their own pace (Chen, et al., 2011; Horn & Staker, 2011; Patrick, 2011; Reigeluth, 2011). However, some teachers were more receptive than others to the idea that the blended learning program supported the increase of differentiated learning. When responding to the anonymous questionnaire, teachers demonstrated how much their perceptions of differentiation varied with responses that ranged from “Differentiation in my classes increased as a result of enacting a blended learning curriculum including Apangea and face-to face instruction” to “Differentiation in my classes decreased as a result of enacting a blended learning curriculum including Apangea and face-to face instruction.”

Observations and meetings revealed that the teachers involved in the implementation of the blended learning program recognized the programs' ability to support learning to varying degrees. For example, Bryce's statement on an Implementation and Observation Form saying that Apangea Math was "cutting into teaching [time]," revealed a lack of belief in the program's potential. To the contrary, Drew's exclamation, "Apangea is the best differentiation tool we have available to us" showed a substantial amount of belief in the programs ability to enhance learning. Snoeyink and Ertmer (2001) suggested that some barriers to the implementation of computer-based instructional technology would be reduced once teachers perceive that using computers can improve student learning.

The literature predicted that teachers' roles would change from knowledge transmitter to coach or facilitator when students are working online (Butler, 2010; Comas-Quinn, 2011; Patrick, 2011; Reigeluth, 2011; Snoeyink & Ertmer, 2001; Zhu, 2010). Classroom observations in this study revealed that teachers sometimes facilitated learning while students were working in Apangea Math by providing one-on-one assistance with challenging content. Other times, teachers worked on unrelated tasks at their desks, distancing themselves from the students during Apangea time, seemingly reluctant to adapt to their new role. Teachers in this study slowly transitioned into the new roles that were predicted by the literature.

Change is difficult and can be hard for people to accept (Butler, 2010; Devaney, 2012). "How teachers accept and adjust to these changes will no doubt influence how students learn" (Snoeyink & Ertmer, 2001, p. 86). For these reasons, administrators

should be aware that different teachers may respond differently to the implementation of new instructional technology programs which can lead to different outcomes.

Recommendations for Future Research

The use of ITS programs has been growing in K-12 education (Horn & Staker, 2011; Mupinga, 2005) presenting a need to research the effectiveness of such programs (Chen, et al., 2011; Means, et al., 2010; Patrick, 2011). After analyzing the data in this study and considering the confirmed findings, lesson learned, and the implications for teachers and administrators, lingering questions remain that naturally point to recommendation for more research.

This study exposed the fact that student achievement did not improve equally in all content standards of mathematics. Lingering questions surrounding the decrease in student achievement in the content standard of Mathematical Processes suggested more research needs to be done to determine why this unexpected decrease in achievement occurred. It would be valuable to do more research to examine the effects of ITS programs compared to face-to-face instruction specifically on students' ability to perform the SPIs that are part of Mathematical Processes (see Appendix A). Additional research could determine if live teachers are better than ITS programs at teaching the nuances of word problems and interpreting the unconventional (but mathematically correct) equations that students create to represent word problems. Furthermore, more research could be done to compare the effectiveness of different ITS programs to each other in promoting student understanding of the content contained in the standard, Mathematical Processes.

Additional research is also needed to examine the effect of ITS programs on student engagement. In order to pair pre to post-student engagement surveys in this study, students put their names on the surveys. This may have influenced students to respond to items based on what they believed were desirable answers instead of reporting their honest perceptions. Future studies may be better served by allowing students to complete the engagement surveys anonymously in order to elicit honest responses. Additional research is also recommended to determine if employing an ITS program over a longer period of time would result in significant changes in students' attitudes towards learning mathematics, as measured by student engagement surveys.

Other recommendations for future research stem from the limited generalizability of this study. The results of this study were limited because the context was restricted to the teaching and learning of Algebra 1 in one urban high school, where the students were predominantly African American and a high percentage were economically disadvantaged. Furthermore, there were many students in this study whose initial skill level was low, and there was an aptitude-treatment effect in favor of lower aptitude students showing greater gains than higher aptitude students. Therefore, additional research is needed to examine the effects of similar programs with more diverse student populations based on ethnicity, socioeconomic status, and ability level.

This study evaluated blended learning delivered according to the rotation model, which featured a fixed schedule that divided instructional time so students spent part of the time engaged in online instruction and part of the time with face-to-face instruction, and the same teacher who moderated the online learning provided the face-to-face

instruction. Additional research is warranted to evaluate the effects of different models of blended learning, which structure the delivery of online and face-to-face instruction differently as described by Horn and Staker (2011) and Patrick (2011). Furthermore, because the design of this study was quasi-experimental, additional research with random assignment is needed to meet higher standards for establishing validity.

Final Thoughts

This study verified that blended learning, integrating an ITS program, Apangea Math, with face-to-face instruction, can result in improved student achievement; particularly, for students with low initial skill levels. The lessons presented to each student by Apangea Math were adaptive and personalized based on each students' level of achievement (D. L. Johnson, 2005). This individualization provided students the opportunity to fill learning gaps, which was important because mathematics is sequential, foundational skills are prerequisites to learning Algebra (National Mathematics Advisory Panel, 2008), and students who are underprepared needed additional support (Stein, et al., 2011). Greater DA test gains made by the intervention group students in this study suggested that the adaptability and personalization of Apangea Math lessons provided support for students and contributed to significant increases in student achievement.

Overall, this technology-based initiative was considered successful, and among students whose initial skill level was low, Apangea Math supported student learning by helping students fill learning gaps. The use of Apangea Math, integrated in a blended learning program, is expected to continue in this high school. While Apangea Math, fueled by artificial intelligence adapted to the needs of the learners, both teachers and

students adapted to a new learning model that may become the new normal. How accepting teachers are of these new ways of teaching can impact how much using computers will improve learning (Snoeyink & Ertmer, 2001).

Additional research is needed to inform the development of such new learning models. These studies of instructional technology and learning models should examine the intended outcomes and expose unintended consequences. Attention to unanticipated consequences is important because educational technology may be approaching a Columbus Effect, meaning benefits and challenges that have not been foreseen could arise from these innovations (Fletcher, 2011).

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Appendices

Appendix A

TN Mathematics Standards SPIs and DA Reporting Categories

TN Mathematics Standards 2009-10 Implementation: Algebra 1	Discovery Assessment: Algebra 1 Reporting Categories
Standard 1 – Mathematical Processes State Performance Indicators:	Standard 1 – Mathematical Processes Reporting subcategories:
SPI 3102.1.1 Interpret patterns found in sequences, tables, and other forms of quantitative information using variables or function notation	SPI 3102.1.1 Interpret Patterns
SPI 3102.1.2 Write an equation symbolically to express a contextual problem.	SPI 3102.1.2 Equation for Contextual Problems
SPI 3102.1.3 Apply properties to evaluate expressions, simplify expressions, and justify solutions to problems.	SPI 3102.1.3 Apply Properties
SPI 3102.1.4 Translate between representations of functions that depict real-world situations.	SPI 3102.1.4 Translate Representation of Function
SPI 3102.1.5 Recognize and express the effects of changing constants and/or coefficients in problem solving.	SPI 3102.1.5 Change Constant/Coefficient Effect
SPI 3102.1.6 Determine and interpret slope in multiple contexts including rate of change in real-world problems	SPI 3102.1.6 Slope in Multiple Contexts
Standard 2 – Number & Operations State Performance Indicators:	Standard 2 – Number & Operations Reporting subcategories:
SPI 3102.2.1 Operate (add, subtract, multiply, divide, simplify, powers) with radicals and radical expressions including radicands involving rational numbers and algebraic expressions.	SPI 3102.2.1 Operate with Radicals
SPI 3102.2.2 Multiply, divide, and square numbers expressed in scientific notation.	SPI 3102.2.2 Compute numbers in scientific notation
SPI 3102.2.3 Describe and/or order a given set of real numbers including both rational and irrational numbers.	SPI 3102.2.3 Describe/order real numbers

Standard 3 – Algebra State Performance Indicators:	Standard 3 – Algebra Reporting subcategories:
SPI 3102.3.1 Express a generalization of a pattern in various representations including algebraic and function notation.	SPI 3102.3.1 Generalize Pattern
SPI 3102.3.2 Operate with polynomials and simplify results.	SPI 3102.3.2 Operate with Polynomials
SPI 3102.3.3 Factor polynomials.	SPI 3102.3.3 Factor Polynomial
SPI 3102.3.4 Operate with, evaluate, and simplify rational expressions including determining restrictions on the domain of the variables.	SPI 3102.3.4 Rational Expressions
SPI 3102.3.5 Write and /or solve linear equations, inequalities, and compound inequalities including those containing absolute value.	SPI 3102.3.5 Linear Equations, Inequalities
SPI 3102.3.6 Interpret various relations in multiple representations.	SPI 3102.3.6 Interpret Relations
SPI 3102.3.7 Determine domain and range of a relation, determine whether a relation is a function and/or evaluate a function at a specified rational value.	SPI 3102.3.7 Domain/Range
SPI 3102.3.8 Determine the equation of a line and/or graph a linear equation.	SPI 3102.3.8 Equation of Line
SPI 3102.3.9 Solve systems of linear equation/inequalities in two variables.	SPI 3102.3.9 Linear Equations w/ 2 Variables
SPI 3102.3.10 Find the solution of a quadratic equation and/or zeros of a quadratic function.	SPI 3102.3.10 Quadratic Equation/Function
SPI 3102.3.11 Analyze nonlinear graphs including quadratic and exponential functions that model a contextual situation.	SPI 3102.3.11 Analyze Nonlinear Graph
Standard 4 – Geometry & Measurement State Performance Indicators:	Standard 4 – Geometry & Measurement Reporting subcategories:
SPI 3102.4.1 Develop and apply strategies to estimate the area of any shape on a plane grid.	SPI 3102.4.1 Estimate Area of Shape
SPI 3102.4.2 Solve contextual problems using the Pythagorean Theorem.	SPI 3102.4.2 Use Pythagorean Theorem
SPI 3102.4.3 Solve problems involving the distance between points or midpoint of a segment.	SPI 3102.4.3 Distance Between Points
SPI 3102.4.4 Convert rates and measurements.	SPI 3102.4.4 Convert Rates/Measures

Standard 5 – Data Analysis, Statistics, & Probability	Standard 5 – Data Analysis, Statistics, and Probability
State Performance Indicators:	Reporting subcategories:
SPI 3102.5.1 Interpret displays of data to answer questions about the data set(s) (e.g., identify pattern, trends, and/or outliers in a data set).	SPI 3102.5.1 Interpret Data Display
SPI 3102.5.2 Identify the effect on mean, median, mode, and range when values in the data set are changed.	SPI 3102.5.2 Change in Data Set
SPI 3102.5.3 Using a scatter-plot, determine if a linear relationship exists and describe the association between variables.	SPI 3102.5.3 Scatter Plot
SPI 3102.5.4 Generate the equation of a line that fits linear data and use it to make a prediction.	SPI 3102.5.4 Equation of Line
SPI 3102.5.5 Determine theoretical and/or experimental probability of an event and/or its complement including using relative frequency.	SPI 3102.5.5 Determine Probability

Appendix B

Voluntary Student Engagement Survey

Name _____

Students' Adaptive Learning Engagement in Mathematics Questionnaire
(Adapted from Velayutham, Aldridge, and Fraser's 2011 survey)

Directions for Students

Here are some statements about you as a student in math class. Please read each statement carefully. Circle the number that best describes what you think about these statements.

Please note that all responses are voluntary and you may leave blank any question you do not wish to answer.

There are no 'right' or 'wrong' answers.

For each statement, draw a circle around

1 if you *Strongly disagree* with the statement

2 if you *Disagree* with the statement

3 if you *Are not sure* about the statement

4 if you *Agree* with the statement

5 if you *Strongly agree* with the statement

If you change your mind about an answer, just cross it out and circle another. Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Your opinion is what is wanted.

	Learning goal orientation	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
<i>In math class...</i>						
1.	One of my goals is to learn as much as I can.	1	2	3	4	5
2.	One of my goals is to learn new math contents.	1	2	3	4	5
3.	One of my goals is to master new math skills.	1	2	3	4	5
4.	It is important that I understand my work.	1	2	3	4	5
5.	It is important for me to learn the math content that is taught.	1	2	3	4	5
6.	It is important to me that I improve my math skills.	1	2	3	4	5

7. It is important that I understand what is being taught to me.	1	2	3	4	5
8. Understanding math ideas is important to me.	1	2	3	4	5
Task Value	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
<i>In math class...</i>					
9. What I learn can be used in my daily life.	1	2	3	4	5
10. What I learn is interesting.	1	2	3	4	5
11. What I learn is useful for me to know.	1	2	3	4	5
12. What I learn is helpful to me.	1	2	3	4	5
13. What I learn is relevant to me.	1	2	3	4	5
14. What I learn is of practical value.	1	2	3	4	5
15. What I learn satisfies my curiosity.	1	2	3	4	5
16. What I learn encourages me to think.	1	2	3	4	5
Self-efficacy	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
<i>In math class...</i>					
17. I can master the skills that are taught.	1	2	3	4	5
18. I can figure out how to do difficult work.	1	2	3	4	5
19. Even if the math work is hard, I can learn it.	1	2	3	4	5
20. I can complete difficult work if I try.	1	2	3	4	5
21. I will receive good grades.	1	2	3	4	5
22. I can learn the work we do.	1	2	3	4	5
23. I can understand the contents taught.	1	2	3	4	5
24. I am good at this subject.	1	2	3	4	5
Self-regulation	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
<i>In math class...</i>					

25. Even when tasks are uninteresting, I keep working.	1	2	3	4	5
26. I work hard even if I do not like what I am doing.	1	2	3	4	5
27. I continue working even if there are better things to do.	1	2	3	4	5
28. I concentrate so that I will not miss important points.	1	2	3	4	5
29. I finish my work and assignments on time.	1	2	3	4	5
30. I do not give up even when the work is difficult.	1	2	3	4	5
31. I concentrate in class.	1	2	3	4	5
32. I keep working until I finish what I am supposed to do.	1	2	3	4	5

Appendix C

Teacher's Implementation and Observation Form

ITS Teacher: _____						
Week: _____ - _____ Block or Section: _____						
Rate the implementation of the ITS program	Mon	Tues	Wed	Thurs	Fri	
<i>Adherence:</i> N/A = no ITS program implemented 1 = Only a few students accessed the program; or only a few used headphones and calculators, and only a few turned in worksheet. 2 = 3 = Approximately half of the students accessed the program; most used headphones & calculators, and most turned in worksheets. 4 = 5 = All the students accessed the program; all used headphones & calculators, and all turned in worksheet.						Weekly Average
<i>Exposure:</i> Record minutes per class period and rate the week based on total for the week. 0 = no ITS program exposure 1 < 40 min; 2 = 41 to 80 min; 3 = 81 to 120 min; 4 = 121 to 160 min; 5 > 161 min						Weekly Rate
<i>Quality of program delivery:</i> N/A = no ITS program implementation 1 = many technical problems 2 = 3 = few or easily fixed technical problems 4 = 5 = smooth delivery; no technical problems						Weekly Average
<i>Participant responsiveness:</i> N/A = no ITS program implementation 1 = most students were not engaged; they were not working in the program. 2 = 3 = half of the students were engaged and working in the program 4 = 5 = all students were engaged and working in the program.						Weekly Average

Describe challenges that you have encountered in implementing the program.

Describe practices that you have used this week that have led to student success.

Estimate the percentage of class time you spent this week doing each of the following during the past week. (These should total 100%).

_____ % Whole class mathematics instruction or demonstration

_____ % One-on-one or small group instruction

_____ % Monitoring students doing group work

_____ % Monitoring students as they work in Apangea Math

_____ % Trouble-shoot technical problems

_____ % Discipline students for inappropriate behavior

_____ % Generate and analyze ITS reports

_____ % Other _____

_____ % Other _____

100 % Total

Appendix D

Anonymous Student Questionnaire

Student Survey Follow-up Questions about Apangea

Here are some statements about ApangeaMath, the online math tutorial program that you used this semester. Please read each statement carefully. Circle the numbers that best describes what you think about these statements. *There are no 'right' or 'wrong' answers.* For each statement, draw a circle around 1 if you *strongly disagree*, 2 if you *disagree*, 3 if you *are not sure*, 4 if you *agree*, and 5 if you *strongly agree*.

	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
1. Apangea helped me understand math that I had difficulty with in the past.	1	2	3	4	5
2. Apangea gave me practice doing math that my Algebra teacher taught in class.	1	2	3	4	5
3. Apangea taught me new math concepts that I had never seen before.	1	2	3	4	5
4. When working in Apangea, I was concentrating deeply on the math in the lessons.	1	2	3	4	5
5. I used Apangea sometimes outside of regular class time.	1	2	3	4	5
6. I think I will learn more in my next math course if it includes an online tutor program like Apangea.	1	2	3	4	5
7. Did you ever participate in the afterschool internet café?	Yes	No			
Answer # 8 to 10 only if you answered "yes" to #7.	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
8. Participating in the internet café helped me understand more math lessons.	1	2	3	4	5

- | | | | | | |
|---|---|---|---|---|---|
| 9. Using the Apangea program and its online features helped me understand more math lessons. | 1 | 2 | 3 | 4 | 5 |
| 10. Listening to the math teacher(s) in the internet café helped me understand more math lessons. | 1 | 2 | 3 | 4 | 5 |

Appendix E

Anonymous Teacher Questionnaire

Teacher Survey Follow-up Questions about Apangea

Survey Questions about the Blended Curriculum, which included Apangea (an online tutor), and face-to-face instruction, used to teach Algebra 1 in spring of 2012.

1. How did the enactment of the blended learning curriculum including Apangea and face-to-face instruction effect the differentiation of instruction in your classes?
 - Differentiation in my classes increased as a result of enacting a blended learning curriculum including Apangea and face-to face instruction.
 - Differentiation in my classes did not change as a result of enacting a blended learning curriculum including Apangea and face-to face instruction.
 - Differentiation in my classes decreased as a result of enacting a blended learning curriculum including Apangea and face-to face instruction.
2. How would you describe the overall student responsiveness to Apangea from January to April 2012?
 - a. None of my students experienced times when they were engaged in the flow of the lessons in Apangea.
 - b. Only a few of my students experienced times when they were engaged in the flow of the lessons in Apangea.
 - c. About half of my students experienced times when they were engaged in the flow of the lessons in Apangea.
 - d. Most of my students experienced times when they were engaged in the flow of the lessons in Apangea.
 - e. All of my students experienced times when they were engaged in the flow of the lessons in Apangea.
3. What percentage of your students do you believe gained mathematical knowledge from using Apangea?
 - a. less than 20%
 - b. at least 20% but less than 40%
 - c. at least 40% but less than 60%
 - d. at least 60% but less than 80%
 - e. 80% or more

4. Now that you know the features of Apangea, do you believe it can be used beneficially in the teaching and learning of Algebra 1 in the future?
 - a. yes
 - b. no

5. If Apangea is made available to you as a teaching tool for Algebra 1 in the future, what amount of class time per typical week would you recommend students use it (assuming class is 90 minutes daily)?
 - a. 0% of the time
 - b. less than 20% of the time (less than 90 minutes per week)
 - c. at least 20% but less than 40% of the time (at least 90 min but < 180 min)
 - d. at least 40% but less than 60% of the time (at least 180 min but < 270 min)
 - e. at least 60% of the time (270 min or more)

6. Are there other online tutorial programs (that you are familiar with) that you would recommend over Apangea?
 - a. yes
 - b. no

Appendix F

TPACK Survey

Teachers of the intervention completed this survey indicating their level of agreement with each statement by circling their selection: SD=*strongly disagree*, D=*disagree*, N=*neither agree nor disagree*, A=*agree*, SA=*strongly agree*.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
TK (Technology Knowledge)					
1. I know how to solve my own technical problems.	SD	D	N	A	SA
2. I can learn technology easily.	SD	D	N	A	SA
3. I keep up with important new technologies.	SD	D	N	A	SA
4. I frequently play around with the technology.	SD	D	N	A	SA
5. I know about a lot of different technologies.	SD	D	N	A	SA
6. I have the technical skills I need to use technology.	SD	D	N	A	SA
7. I have sufficient opportunities to work with different technologies.	SD	D	N	A	SA
CK (Content Knowledge)					
8. I have sufficient knowledge about mathematics.	SD	D	N	A	SA
9. I can use a mathematical way of thinking.	SD	D	N	A	SA
10. I have various ways and strategies of developing my understanding of mathematics.	SD	D	N	A	SA
PK (Pedagogical Knowledge)					
11. I know how to assess student performance in a classroom.	SD	D	N	A	SA
12. I can adapt my teaching based upon what students currently understand or do not understand.	SD	D	N	A	SA
13. I can adapt my teaching style to different learners.	SD	D	N	A	SA

14. I can assess student learning in multiple ways.	SD	D	N	A	SA
15. I can use a wide range of teaching approaches in a classroom setting.	SD	D	N	A	SA
16. I am familiar with common student understandings and misconceptions.	SD	D	N	A	SA
17. I know how to organize and maintain classroom management.	SD	D	N	A	SA
PCK (Pedagogical Content Knowledge)					
18. I can select effective teaching approaches to guide student thinking and learning in mathematics.	SD	D	N	A	SA
TCK (Technological Content Knowledge)					
19. I know about technologies that I can use for understanding and doing mathematics.	SD	D	N	A	SA
TPK (Technological Pedagogical Knowledge)					
20. I can choose technologies that enhance the teaching approaches for a lesson.	SD	D	N	A	SA
21. I can choose technologies that enhance students' learning for a lesson.	SD	D	N	A	SA
22. Courses I have taken and/or professional development have caused me to think more deeply about how technology could influence the teaching approaches I use in my classroom.	SD	D	N	A	SA
23. I am thinking critically about how to use technology in my classroom.	SD	D	N	A	SA
24. I can adapt the use of the technologies that I am learning about to different teaching activities.	SD	D	N	A	SA

TPACK (Technological Pedagogical Content Knowledge)					
25. I can use strategies in my classroom that combine content, technologies and teaching approaches that I learned about in my coursework and/or professional development.	SD	D	N	A	SA
26. I can choose technologies that enhance the content for a lesson.	SD	D	N	A	SA
27. I can select technologies to use in my classroom that enhance what I teach, how I teach and what students learn.	SD	D	N	A	SA
28. I can provide leadership in helping others to coordinate the use of content, technologies and teaching approaches at my school and/or district.	SD	D	N	A	SA
29. I can teach lessons that appropriately combine mathematics, technologies and teaching approaches.	SD	D	N	A	SA

Adapted from Schmidt, D. A., Baran, E., Thompson, A. D., Koehler, M. J., Mishra, P., & Shin, T. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, 42(2), 123-149.

Appendix G

Parent Permission Form

Requesting Student Participation in a Study

Dear Parent/Guardian:

During the spring semester 2012, [the School] will begin a program designed to enhance the teaching and learning of mathematics called Apangea Math. Students in Algebra 1 classes will learn to access and use Apangea Math, an online intelligent tutor system. This program will be available to students to study mathematics any time from any computer with internet access. Apangea Math keeps track of each student's usage and progress within the program, and students earn points for their progress that can be redeemed for prizes.

In an effort to evaluate the effects of this new program, we are asking the parent/guardians of Algebra 1 students to give permission for their students to participate in a study. The study will look at students' usage and progress within the Apangea Math program, their achievement on Discovery Assessments and End-of-Course exams, and their responses to Student-Engagement surveys. The Discovery Assessments and Student-Engagement surveys will be conducted as pre and post assessments in order to compare changes in students' knowledge and engagement in mathematics. Each administration of the survey is expected to take just 10 to 20 minutes. Classroom observations will be made to evaluate processes and activities that take place. All student data will remain confidential; their identities will in no way be used. The collection of this data will help inform instructional decisions in the future.

There is a copy of the survey and a classroom observation form in the principal's office, if you wish to review them. Each student's participation in the survey is entirely voluntary. There are no costs or risks to the students in completing the survey. Each student will be given the option of leaving blank any question that he or she prefers not to answer. Each student who returns a completed permission form to participate in the study will be entered in a drawing for a gift card.

If you have questions at any time about the study, you may contact the researcher, Karen K. Lucas, at (252) 917-4198 or the University of Tennessee's Office of Research Compliance Officer at (865) 974-3466.

I give permission for my student, _____ to
participate in this study. Student's Name

Parent or Guardian's Name

Parent or Guardian's Signature

Appendix H

Student Assent

When Student-Engagement surveys are administered, teachers/administrators will say the following to students:

Today, I am asking you to complete a brief survey. It will take only 10 to 20 minutes to complete. Your participation and all of your responses are voluntary. There is no penalty if you choose to leave any answer blank.

The survey contains some statements about you as a student in math class. *There are no 'right' or 'wrong' answers.*

For each statement, draw a circle around

- 1 if you *Strongly disagree* with the statement
- 2 if you *Disagree* with the statement
- 3 if you *Are not sure* about the statement
- 4 if you *Agree* with the statement
- 5 if you *Strongly agree* with the statement

If you change your mind about an answer, just cross it out and circle another. Please read each statement carefully. Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Your opinion is what is wanted.

When you have completed the survey, please put down your pencil or pen and get out a book to read.

Thank you, your participation is appreciated.

Appendix I

Teachers' Informed Consent Statement

Teaching and Learning Algebra 1 via an Intelligent Tutor System:
Effects on Student Engagement and Achievement

INTRODUCTION

You are invited to participate in a research study on the implementation and effectiveness of teaching and learning Algebra 1 via an intelligent tutor system (ITS). The expectation is that this program will increase student engagement and improve achievement.

During the spring semester 2012, Algebra 1 students will use TouchPad tablets during math class to access an intelligent tutor system (ITS). The comparison group will be previous classes of Algebra 1 students who were taught with typical teacher and textbook instruction. I will assist teachers in learning how to facilitate student learning via the ITS program and document processes and activities as they take place. I will also collect progress and achievement data per class. Thus, the purpose of the research is to provide practical information about the implementation of the program and its effectiveness in order to inform decision makers about the use of similar programs in the future.

INFORMATION ABOUT PARTICIPANTS' INVOLVEMENT IN THE STUDY

This innovative instructional program provides the Algebra 1 students with HP TouchPad tablets and access to Apangea Math, an intelligent tutor system (ITS). Apangea Math's use of artificial intelligence (AI) differentiates it from many other computer-assisted instruction (CAI) programs and enables it to adapt and customize each student's learning experience. Apangea Math has reporting features which allow administrators and teachers to generate statistics regarding students' usage and progress. Overall, the ITS program is expected to increase student engagement and improve student achievement in mathematics.

Administrators have asked for this program to be evaluated, thus, the main purpose of the study is to provide practical information about the implementation of the program and analyses of its effectiveness. A program evaluation report will be compiled to disseminate findings to administrators to inform their decisions about the use of this type of program in the future. This evaluation will also be used to satisfy course requirements for Program Evaluation II, and may be submitted for publication or presentation via professional education journals or conferences. . The data collected will also be used for the principal investigator's dissertation.

This spring, Algebra 1 students will use the HP TouchPad tablets during math class to access the Apangea Math ITS program. They will not be permitted to take the tablets home due to security concerns for the students and the equipment, but they will be able to access their Apangea Math ITS accounts at any time from any computer with internet access. The comparison group received typical teacher and textbook style classroom instruction and no access to any ITS program during prior semesters.

_____ Participant's initials

The student data that will be collected and analyzed will include the following:

- Archived data for individual students: Discovery Assessments and End-of-Course (EOC) test scores that have been de-identified for students who took Algebra 1 in semesters prior to spring 2012.
- Current data for individual students: Discovery Assessments, EOC test scores, Student-Engagement survey data, and online Apangea Math ITS data for those students who provide parent permission and student assent.
- Current data at the classroom level: Classroom means for the Discovery Assessments and EOC tests for each current classroom after the data has been de-identified.
- In the summer of 2012, collect de-identified data for individual students: Discovery Assessments and End-of-Course (EOC) test scores that have been de-identified for students who took Algebra 1 during the intervention period (spring 2012).

This school year is the third year for the administration of Discovery Assessments and the current version of the Algebra 1 EOC examination. The Apangea Math ITS data includes statistics such as the amount of time students spend online using the program, points earned, and lessons passed. The self-reported Student-Engagement data will be generated for the students near the beginning of the intervention and again near the end of the semester from the administration of a survey adapted from the instrument developed by Velayutham, Aldridge, & Fraser (2011). This instrument was thoughtfully constructed, was tested for reliability and validity, and is expected to take just 10 to 20 minutes to administer.

The teachers who incorporate the Apangea Math ITS program in their classes will be asked to complete observation forms providing data regarding fidelity of implementation, teachers' role in facilitating the program, and other noteworthy observations. Teacher-participants will also be asked to complete a modified version of the TPACK (technological pedagogical and content knowledge) survey to gauge their knowledge of teaching and technology. Participation in teachers' meetings and observations of Algebra 1 classes throughout the spring 2012 semester will provide additional information for the documentation of the implementation process for the ITS program.

The collected data will be used first to describe the classes who received the ITS program instruction and those who received the typical teacher and textbook instruction. Next, the instruction that actually takes place via the implementation of the ITS program will be documented. Finally, program outcomes will be compared to program objectives including to what extent classes' achievement in mathematics improved and to what extent students displayed and reported their engagement with the program.

In analyzing the outcomes of the program, the achievement gains of classes who received the ITS instruction will be compared to classes who received the typical classroom instruction. Changes in student engagement will be analyzed. The role of teachers, elements of program implementation, and correlations between variables will be examined.

RISKS

The risks involved with the participants in this study are minimal. Inadvertent release of the surveys, observation forms, or notes may be a risk; however, confidentiality is ensured by giving student-participants codes and teacher-participants pseudonyms.

_____ Participant's initials

All original surveys and observation notes will be stored in a locked location in the principal investigators' home or office. The principal investigator will be the only one with a key. Therefore, confidentiality is ensured and risks are minimal.

BENEFITS

Other than the chance for student-participants to win a gift card for returning their permission forms, no financial benefit will be awarded to participants. Participants in the study will contribute to the body of knowledge regarding teaching and learning via Intelligent Tutor Systems. The desired outcome is to provide practical information to the local administrators and to the larger educational community to inform decision making about mathematics instructional programs.

CONFIDENTIALITY

All data will be kept confidential and all students, teachers, schools, and the system will be kept anonymous in any publication except when given written permission to mention the system by the [School District's] Research Committee.

CONTACT INFORMATION

If you have questions at any time about the study or the procedures, you may contact the researcher, Karen K. Lucas, at (252) 917-4198. If you have questions about your rights as a participant, contact the Office of Research Compliance Officer at (865) 974-3466.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed.

CONSENT

I have read the above information. I have received a copy of this form. I agree to participate in this study.

Participant's signature _____ Date _____

Investigator's signature _____ Date _____

Vita

Karen Kerner Lucas grew up in Havertown, Pennsylvania and graduated from Archbishop John Carroll High School in Radnor, Pennsylvania. She earned her Bachelor of Science degree in Food Industry from Delaware Valley College in Doylestown, Pennsylvania. After working in the food industry and accounting, she discovered her desire to teach. She taught middle grades mathematics in North Carolina from 2005 to 2009 and earned her Master's in the Art of Teaching degree concentrating in middle grades mathematics from East Carolina University in Greenville, NC in 2007. She taught ninth grade Algebra 1 in Tennessee in 2009 – 2010 and began working on her Doctorate of Philosophy degree in Teacher Education specializing in Mathematics Education at the University of Tennessee in Knoxville in 2010. While completing PhD coursework, she was employed as an associate editor for the *Journal of Curriculum and Instruction* and as an Algebra 1 consultant. In addition to her PhD, Karen completed additional courses to earn a graduate certificate in Evaluation, Statistics, and Measurement from the University of Tennessee. Currently, Karen is a system-wide Secondary Numeracy Coach for a school district in Tennessee.