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Personalized Geometry Instruction: A Mixed Methods Action Research Study Implementing an Adaptive Web-Based Learning Environment to Support High School Students' Geometry Problemsolving Skills

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Personalized Geometry Instruction: A Mixed Methods Action Research Study Implementing an Adaptive Web-Based Learning Environment to Support High School Students' Geometry Problem-Solving Skills

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DEDICATION

This dissertation is dedicated to the people who have offered me nothing but continuous support throughout this journey.

First, I dedicate this to my children, Andrew and Abby. Your inquisitive nature, your understanding of an imperfect mother continuously on a quest for new knowledge, and your unconditional love are inspiring. Every choice I make is for the betterment of you. I hope my journey has inspired you both to strive for your own dreams.

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ABSTRACT

The purpose of this action research study was to evaluate the implementation of an adaptive web-based learning environment to personalize geometry instruction and practice for high school students at a private school in North Carolina. This study was guided by the following three research questions: (1) How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry? (2) How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept? (3) What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry?

This mixed methods action research involved the implementation of an adaptive web-based learning environment with 44 students in Grades 9–10 from three geometry classes. The implementation took place over a 7-week period, during the spring semester of 2021, and it covered two different geometry units: quadrilaterals and similar triangles. Geometry instruction was supported by integrating the adaptive web-based learning environment, IXL, into teaching as a supplemental piece as units were taught to students. It was used for individualized practice for students both in and out of the classroom. Quantitative data were obtained using a content knowledge pre- and post-assessment, as well as student questionnaires, and qualitative data were obtained using student interviews. Quantitative data were analyzed using descriptive statistics, paired sample *t* tests, and Wilcoxon signed-rank tests and qualitative data were analyzed using inductive/thematic analysis. Overall findings showed using the IXL platform as a geometry supplement helped students improve their learning of geometry. The majority of the students were found to have a positive opinion of IXL when used to help with learning geometry. Additionally, IXL helped improve students' motivation to learn geometry, mathematics self-efficacy, anxiety, and self-concept.

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INTRODUCTION

National Context

The National Assessment of Educational Progress (NAEP) is an assessment used to demonstrate the big picture of mathematics achievement throughout the United States. There are three levels reported within these assessments: basic, proficient, and advanced. The 2017 Mathematics Framework for the NAEP indicated the proficient level "represents solid academic performance for each grade assessed. Students reaching this level have demonstrated competency over challenging subject matter" (U.S. Department of Education, 2017, p. 1). Scores on the mathematics assessments range from 0 to 300, with the advanced level beginning at a score of 216. The results of the 2015 mathematics assessment showed only 10% of students in Grade 12 reached a score of 196 or higher, which indicates less than 10% of students in Grade 12 tested across the United States in 2015 had the ability to perform problems involving geometric thinking, including logical reasoning and proofs. Furthermore, only 25% of students in Grade 12 actually scored at or above the proficient level on the 2015 mathematics assessment. Many of the topics missed were related to geometry (U.S. Department of Education, 2017).

Mathematical proofs are arguments verifying a statement is true by deductive reasoning (Selden & Selden, 2003). Though proofs continue to be a part of the mathematics curriculum throughout the United States, students continue to have trouble writing their own proofs (Healy & Hoyles, 2000; Senk, 1985; Weber, 2001; Yang & Lin, 2008), particularly in geometry (Miyazaki, Fujita, Jones, & Iwanaga, 2017). Students struggle to read through proofs that have been given to them (Inglis & Alcock, 2012) and may still believe some statements that are not necessarily true based on the information they have at hand (Miyazaki, Fujita, Jones, & Iwanaga, 2017). Students are often ill prepared to work through the reasoning steps needed for proofs (McCrone & Martin, 2004), which is indicative of not having the necessary critical thinking skills or the ability to think logically through problems. Students usually do not try to understand all of the surface information of proofs (Weber, 2015). The skill of proof writing is important for students because it helps with understanding throughout a geometry course as well as within other mathematical areas (McCrone & Martin, 2004), abilities students will need later in math courses and in life after they graduate from high school.

There has been a significant amount of research on students' difficulties in understanding proofs. Some of the difficulties students have with proofs stem from their inability to comprehend what they read (Yang, 2012). Battista and Clements (1995) found students need to able to visualize what they are trying to prove and be able to think empirically to further their levels of geometric thinking, and Robotti (2012) stated "natural language provides students with different kinds of help for problem solving" (p. 434). Students need to be taught how to carefully think about what information they have been given and what they have read in order to move through the logical structure of a proof (Alcock, 2009).

Being able to comprehend what is read mathematically is important in math, as well as in understanding and writing proofs (Yang & Lin, 2008). Reading through proofs and assessing the content of a proof is fundamental to how a person can further understand mathematics, yet many students tend to only focus on surface-level information (Selden & Selden, 2003). Students who are able to understand the basic terms of a proof can go beyond that surface-level thinking (Yang & Lin, 2008). It is important to be able to help students navigate their way through proofs and solve problems in geometry in order to enhance critical thinking skills.

One major educational technological intervention that can help with proofs and learning geometry has been the implementation of adaptive web-based learning environments. These systems are being used more often within the field of education (Phillips et al., 2020; Kolb & Kolb, 2005). The draw of these learning environments is the fact that they provide individualized support to students, taking into account their personal traits (Normadhi et al., 2019), ability level (Khosravi et al., 2020), and motivation (Flores et al., 2012). Adaptive web-based learning environments can help students gain a better understanding of the way they learn (Khosravi et al., 2020) and can give teachers better insight into what may help each individual student learn (Hamada & Hassan, 2017).

A number of adaptive web-based learning environments have been used to help promote learning within the mathematics classroom, including when teaching geometry. Dynamic geometry environments have helped both students and teachers (Komatsu et al., 2017; Leikin & Grossman, 2013). Using this type of learning system can help students explore proofs before having to make their own justifications in proofs, allowing them to gain further understanding before they start the proof-writing process (Marrades & Gutierrez, 2000). Adaptive web-based learning environments have also helped teachers ask better questions of their students for better understanding (Hahkioniemi, 2017). Using web-based learning systems can provide positive experiences for students and teachers when it comes to writing proofs (Komatsu et al., 2017; Leikin & Grossman, 2013).

Local Context

This research took place during the spring of 2021 at an independent, college preparatory, K–12 school in North Carolina. This school consists of about 1,600 students in transitional kindergarten through Grade 12. The majority of students are Caucasian, with almost 29% of the school's population is African American, Asian American, Hispanic, Middle Eastern, multiracial American, Native American, and Pacific Islander. There are roughly 600 students in Grades 9 through 12. Approximately 15% of students receive financial aid and about 10% of students were fully remote for the entire 2020–2021 school year. I have learned over the last 19 years of teaching geometry that this subject is the most challenging for my students. The ability to think logically and use reasoning ability to solve problems has become increasingly difficult for my students. For all of the geometry teachers at this school, each end of semester survey reflects that at least 75% of students say geometry has been the most challenging math class they have had to take throughout their schooling.

One of the core values at this school is "that students should be astute thinkers and persistent, creative problem solvers" (Providence Day School, n.d., para 2). Problem-solving in geometry addresses this value, but not without great challenges for the students. My students continuously struggle with learning to solve geometry problems. Even the "best" math students always find this subject challenging. Thinking logically is a struggle for most students. Furthermore, the inability for students to "see" the math is not evident. They have difficulty understanding the material; reading through all of the definitions, postulates, and theorems given to them; and comprehending what it is they are trying to accomplish.

The geometry courses contain a focus on problem solving, with proofs being a big part of teaching. We dive into proofs and problem solving within weeks of starting the course, and continue throughout the school year. There is algebra throughout as well, but the main theme is problem solving with an emphasis on proof writing. The geometry teachers at this school have continued to notice a negative difference in grades between other math courses and geometry. For some students, it is not uncommon to see a difference of at least one letter grade. This causes students to enter geometry believing they are going to struggle regardless of how hard they try or what they do. They begin the year believing geometry is going to be difficult and impossible to understand, even though the majority of the students do not know what a proof is or what geometry entails. Through end of semester surveys, geometry teachers have discovered students consider problem solving and proofs to be the most challenging parts of geometry.

Steps have been taken to address the issue of proof writing at this school. Teachers have approached the concept with different mindsets in the hope of being able to reach every type of learner. We have created notecards for every definition, postulate, property, and theorem presented in order to construct “puzzle proofs.” We have also created flow charts and diagrams for proofs to help students “see” how one step flows to the next. Nevertheless, we still see an increase in the number of students having difficulty. Students have created Quizlets and we have done numerous study sessions, all with the goal of trying to help improve students’ ability to solve problems and write proofs. We have even begun with “algebraic proofs” as a way to relate the steps of a geometric proof to the steps of solving an algebraic equation. The majority of students want to be successful and are willing to try whatever suggestion is given to them. Regardless of the interventions we have attempted, student results have not improved. We continue to see students struggle to solve problems and write proofs, even when it is clear they have a good grasp of the concepts. It is evident there is a need for students to get help with writing proofs and problem solving in geometry.

Statement of the Problem

Students in Grades 9 and 10 at a private school in North Carolina are struggling to learn and solve problems in geometry.

Purpose Statement

The purpose of this action research study was to evaluate the implementation of an adaptive web-based learning environment to personalize geometry instruction and practice for high school students at a private school in North Carolina.

Research Questions

The following are the three research questions that guided this study:

1. How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry?
2. How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept?

3. What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry?

Subjectivities and Positionality

The beginning of the 2020–2021 school year marked my 19th year as a high school math teacher. During this school year, I was in my sixth year at an independent, college preparatory school in North Carolina chosen for this study. I have taught all levels of math from algebra to advanced pre-calculus, but I have always taught geometry. I received my math degree from Queens College in Charlotte, NC, in 2002 and my Masters of High School Math Education from the University of North Carolina at Charlotte (UNCC) in 2006.

The change in technology over the years has been incredible. When I began my master's program at UNCC in the spring of 2003, I was commuting to classes at night and students turned in all assignments on paper. Within 2 years, my program began to be offered as an online version, where students could do the entire program from a computer. When I began teaching 19 years ago, I used a whiteboard and dry erase markers. I felt this was advanced because I was not using chalk and chalkboards. I used an overhead projector and hoped the light bulb would last the entire year. I now have access to a laptop, iPad, Smart Board, and almost any new piece of technology I am willing to try. I hand wrote the very first semester exams I ever gave to students, but now everything is typed in a Google or Word document using math programs. Our attendance, communication, grades, handouts to students, and even some instruction are all completed online using technology.

It is extremely important for educators to ensure they are able to grow and adapt as new technology continues to emerge. In order to prepare my students to be active members of their communities when they leave my classroom, I must do my best to keep up with the technological changes that continue to take place in the field of education. I believe I have to be a lifelong learner in order to be a successful teacher, and technology is one of the most important areas in which I must continue to be invested. I feel it is imperative for me to continue to learn about the available technology and what might help my students.

My goal as an educator is to be able to help my students think critically and be able to use what they learn in the future. I want my students to learn skills that are beneficial and applicable to the world they will be living in once they finish school. In order for this to happen, I needed to focus my research on the questions I was trying to answer rather than trying to stick to one specific research method. Pragmatism focuses on the fact that you can choose a method simply because it fits what you are trying to research (Mertens, 2012). I also believe different worldviews need to be considered and that I need to take into account the fact that each assumption a person has can help me answer my research questions. For me, pragmatism is the paradigm that fit my action research the best because it enabled me to use different methods, views, assumptions, data collection, and data analysis (Creswell, 2014). I was able to gather quantitative data through a content knowledge pre- and post-assessment, as well as through student questionnaires. I also gathered qualitative data from students through interviews. Using mixed methods research enabled me to interpret the data in a number of different ways.

It is important for me to help my students as much as possible, and because of this, I often want to help them solve problems. When it comes to learning geometry, this is especially true. Many students want to have me work through each problem with them. I needed to keep in mind that I had to let myself continue to be the teacher as the students worked through the problems they were given. I could not let my role as the researcher affect the way I acted as the educator. If I wanted correct data, I had to keep my teaching as normal as it would be without the research being conducted. I continued to treat my students the same as I normally did while grading, conducting normal lessons, and offering my help in and out of the classroom. It was important to remain the teacher in the classroom when I was not collecting data and to be the researcher when I was conducting student interviews, content knowledge pre- and post-assessments, and student questionnaires.

I tend to hold the view that all students struggle with learning geometry. I needed to remind myself continuously that some students may not have been struggling and may not have needed any help. I needed to make sure I was aware of my position as a teacher and a researcher throughout my study because I was an insider. I needed to put aside my personal beliefs and those beliefs I hold as an educator and use only the concrete data I collected as well as the themes that emerged throughout the research.

Definition of Terms

Adaptive Web-Based Learning Environment. An adaptive web-based learning environment is a system that provides individualized support to students, taking into account their personal traits (Normadhi et al., 2019), ability level (Khosravi et al., 2020), and motivation (Flores et al., 2012). Adaptive web-based learning environments can help students gain a better understanding of the way they learn (Khosravi et al., 2020) and can give teachers better insight into what may help each individual student learn (Hamada & Hassan, 2017).

Geometry self-efficacy. Self-efficacy is an individual's beliefs about their ability to successfully perform a specific task (Bandura, 1986). Mathematical self-efficacy is an individual's beliefs about their ability to successfully perform mathematical tasks (Hackett & Betz, 1989). Mathematics self-efficacy can accurately predict mathematics achievement (Recber et al., 2018). Similarly, geometry self-efficacy reflects an individual's beliefs about their ability to successfully perform geometry tasks.

IXL. IXL is an adaptive web-based learning environment that generates questions at the correct level for each individual student and adapts to the answer given when working through problems. Students are unlikely to see the same question twice because the problems are algorithmically generated. This gives students the opportunity to have a limitless supply of practice. IXL personalizes the learning experience for each student by using the answers students provide as well as real-time information, such as how long it takes to answer a specific question. The questions on a specific skill get more difficult as students continue to answer correctly. If students answer incorrectly, they are offered guidance and support. The questions build on what the students have already mastered.

Mathematics anxiety. Anxiety relates to the reactions a person has when he or she thinks about or performs some task (Stankov, Lee, Luo, & Hogan, 2012). Anxiety in mathematics relates to negative feelings of distress, nervousness, and hesitation that students experience when engaging with mathematics (Ramirez, Shaw, & Maloney, 2018). It tends to make students worry and dislike the subject (Olson & Stoehr, 2018; Ramirez et al., 2018), and has long been related to a student's achievement in mathematics (Ramirez, Gunderson, Levine, & Beilock, 2013). Mathematics anxiety has been shown to increase as students get older (Olson & Stoehr, 2018).

Proofs. Proofs have been a main learning objective of geometry courses throughout the history of education and yet remain one of the hardest concepts for students to understand (Senk, 1985). Mathematical proofs are typically referred to as an argument proving a statement is true by deductive reasoning (Selden & Selden, 2003). Proofs given in high school are generally believed to help teach students how to think logically and critically as well as how to justify the mathematical statements they make (Herbst & Brach, 2006). For the purpose of this action research, proofs refer to formal two-column proofs.

Proof-writing ability. A student's ability to write a two-column proof is determined by whether or not they can take given information; apply appropriate geometric theorems, definitions, postulates, and properties; and reason deductively step by step down to the conclusion of the proof (Wong et al., 2011).

Student self-concept. A student's self-concept is the way he or she perceives himself or herself (Stankov et al., 2012). A student's mathematical self-concept is the way he or she perceives his or her ability to be successful in or learn the subject of mathematics (Wilkins, 2004). A student's mathematical self-concept has been found to be related to his or her successfulness in the subject (Pajares & Miller, 1994; Wilkins, 2004).

Student engagement. Student engagement in mathematics can be defined as a student's investment in and his or her effort given towards understanding and mastering the content (Newmann, Wehlage, & Lamborn, 1992). It has been found that students who work harder are more engaged in their learning process (Newmann et al., 1992).

Student interest. A student's interest in mathematics can be defined as the attention he or she gives to learning mathematics as well as the willingness to actively participate in the learning of mathematics (Meke, Jailani, Wutsqa, & Alfi, 2019). A student's interest in mathematics can have an affect on their attitude about the subject (Degenhart et al., 2007).

Student motivation. According to Glynn and Koballa (2006), motivation is "an internal state that arouses, directs, and sustains students' behavior" (p. 25). Student motivation in mathematics can be linked to personal goals (Keys, Conley, Duncan, & Domina, 2012), and can be a factor in whether or not students are successful in mathematics courses (Herges, Duffield, Martin, & Wageman, 2017).

CHAPTER 2

REVIEW OF THE LITERATURE

Introduction

The purpose of this action research study was to evaluate the implementation of an adaptive web-based learning environment to personalize geometry instruction and practice for high school students at a private school in North Carolina. The related literature review was guided by the following research questions: (1) How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry? (2) How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept? (3) What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry?

Literature Review Methodology

When looking for relevant literature, I first searched for geometry and proofs, including all I could find. I excluded articles not related to math instruction and adaptive learning environments. I then excluded articles published before the year 2010, unless they were written by a well-known author for the subject or a highly cited author.

The methodology for the literature search was guided by the three research questions. In order to find resources for the literature review, I used the ERIC and JSTOR electronic databases. I was also able to access further resources by using the Google Scholar website. I began with the following keywords: geometry, high school, proofs, technology. I narrowed my search by using the following key phrases within these databases: (a) high school geometry proof, (b) student math/geometry achievement, (c) adaptive web-based learning environments, (d) adaptive web-based learning environments and K–12 mathematics education, and I individualized differences/support with math. I also mined the reference lists of the articles I found to look for other relevant articles.

The focus of the literature review is on adaptive web-based learning environments and K–12 mathematics education. It is organized into two major sections. The first section covers K–12 mathematics education. It includes mathematical struggles for students, student math achievement, and challenges for mathematics teachers. It also includes a discussion of strategies that have been used and their impact on student knowledge in geometry and two-column proof writing. It covers how the mathematics teacher has been involved in the process of student proof writing with regard to student math achievement and adaptive web-based learning environments. The second section relates to web-based learning environments. It includes how these web-based learning environments have been used in education as well as how they have been used in mathematics education, including geometry. It also covers the impact of these web-based learning environments on math achievement, and more specifically, geometry achievement.

Mathematics Learning and Teaching in K-12

The National Assessment of Educational Progress (NAEP), also known as the Nation's Report Card, provides assessments that show the big picture of mathematics achievement throughout the United States. The results of the 2015 mathematics assessment showed 12^{th}-grade math scores had decreased since 2013 (U.S. Department of Education, 2017). In addition, students with low-level and middle-level mathematics performance showed a decrease in mathematics scores. Furthermore, the 2019 NAEP reported that though the scores for fourth graders increased slightly from 2017 to 2019, the scores for eighth graders decreased during this timeframe. This trend shows that as students progress in grade levels throughout school, they continue to struggle in the area of mathematics. In a math course like geometry, the struggle can be even more daunting (Adolphus, 2011; Kaufmann, 2011). Looking at the individualized student support that is necessary in mathematics and the teaching of mathematics can help to shed light on this growing issue. This review of current literature is used to address both of these topics and their impacts.

Individualized Support in Mathematics

Though writing proofs continues to be a part of the mathematics curriculum throughout the United States, students continue to have trouble writing proofs (Healy & Hoyles, 2000; Senk, 1985; Weber, 2001; Yang & Lin, 2008), particularly in geometry (Miyazaki, Fujita, & Jones, 2017). For this research, it is important to look at student struggles, as well as student motivation and how it affects mathematics achievement, the prior knowledge a student may possess, geometry self-efficacy and how it relates to mathematics achievement, the importance of proofs in geometry, and the reading comprehension involved in proofs.

Student Struggles

The results from the 2019 NAEP are difficult to digest and point to a persistent problem in the United States (U.S. Department of Education, 2019). Two persistent struggles for students in mathematics are anxiety and proof-writing.

Student Anxiety. Anxiety is related to the reactions of a person when thinking about or performing a task (Stankov et al., 2012). Mathematics anxiety relates to negative feelings of distress, nervousness, and hesitation that students experience when engaged with mathematics (Ramirez, Shaw, & Maloney, 2018). This anxiety is one reason students tend to struggle in the subject (Heyder et al., 2019; Ramirez et al., 2018). Mathematics anxiety tends to increase as students move into secondary school (Olson & Stoehr, 2018) and it affects mathematics achievement negatively (Ramirez et al., 2018). Addressing mathematics anxiety in secondary schools but identifying it in earlier grades can help students have better achievement and not shy away from future math courses (Ramirez et al., 2013).

Writing proofs. Writing proofs is an important skill for students to learn because it helps them develop important critical thinking skills. Students in secondary schools across the United States struggle to understand mathematical proofs (Inglis & Alcock, 2012; Miyazaki, Fujita, Jones, & Iwanaga, 2017; Yang & Lin, 2008) and demonstrate low levels of achievement in writing mathematical proofs (Senk, 1985; Yang, 2012; Yang & Lin, 2008; Zazkis et al., 2016). Further, students who do not struggle in other areas of mathematics can have difficulty with the abrupt transition to writing proofs

(Moore, 1994). Because mathematical proofs appear in many secondary school math courses, it is important for students to be able to achieve success in this area.

Student Motivation

Glynn and Koballa (2006) define motivation as "an internal state that arouses, directs, and sustains students' behavior" (p. 25). Motivation is an important factor that affects learning (Herges et al., 2017; Keys et al., 2012) and influences achievement (Herges et al., 2017; Keys et al., 2012). Motivating students toward learning mathematics is more challenging due to the lack of understanding, poor performance (Bhagat & Chang, 2015), and students not enjoying the subject (Muir, 2019). The following sections address student ability levels, technology, and interest and attitude, as each is related to student motivations in a math course.

Student Ability. Pajares and Kranzler (1995) found a student's mathematical ability has a strong effect on their mathematical performance. Students with a low ability level in mathematics can struggle to stay motivated in the mathematics classroom (Heyder et al., 2019). Additionally, students with a low mathematical ability may find it difficult to solve problems (Alghadari et al., 2020).

Student Self-Concept. A student's self-concept is the way he or she perceives himself or herself (Stankov et al., 2012). A student's mathematical self-concept is the way he or she perceives his or her ability to be successful in or learn the subject of mathematics (Wilkins, 2004). It has been determined that a student's self-concept is a good predictor of a student's academic achievement (Stankov et al., 2012). Students' feelings about their own ability can affect not only their performance on a task, but also their effort, anxiety level, and willingness to try difficult challenges (Pajares & Miller, 1994). In a study of almost 290,000 students from over 41 different countries, Wilkins (2004) determined that students with a positive self-concept had better academic achievement. Additionally, in a research study of 350 students, Pajares and Miller (1994) found that self-concept was a better predictor of student ability in mathematics than other variables.

Technology. Technology can be a major motivator for students when learning mathematics. Technology keeps students engaged with the learning (Herbst & Brach, 2006; Ko & Knuth, 2009; Segal et al., 2018). In a quasi-experimental research study conducted by Ojimba, Gogo, and Chetachi (2020), it was found that using an adaptive we-based learning environment helped improve the attitude of students when learning mathematics. Furthermore, students like using technology to explore and investigate (Koyuncu et al., 2015; Segal et al., 2018). Including technology, such as gamification, in math education can help keep students engaged and can encourage them to do well (Inan et al., 2020; Mohamad et al., 2018). Finding the technology that motivates students can be a great way to individualize support in a math classroom.

Though technology can be a factor for increasing motivation, it is important to realize it is not the only solution and teachers must be careful when they implement technology within their classrooms (Wallace & Witus, 2013). Using technology can help students learn math, but it will not necessarily guarantee that every student learns the math they are supposed to learn (Montrieux et al., 2016). Wallace and Witus (2013) noted a lot of time is needed to begin using a new technology within a course, which can be frustrating for both students and teachers. In addition, some technology can be more distracting than motivating, harming a student's chance to improve their math achievement (Perry & Steck, 2015). For example, Phillips et al. (2020) found many students using ALEKS, an adaptive web-based learning environment for mathematics, had a low usage reported and did not improve their learning of the subject. Further, Perry and Steck (2015) found using iPads in a geometry classroom was distracting, led to off-task behaviors, and did not help improve achievement in the class. It has been determined that students learn better when there is a blend of adaptive web-based learning environments in conjunction with teacher-led instruction (Ojimba, Gogo, & Chetachi, 2020; Lin, Yu, Hsiao, Chang, & Chien, 2020). Integrating the right technology in the right way is important for increasing student motivation.

Interest and Attitude. Student interest in mathematics can be defined as the attention a student gives to learning mathematics as well as the willingness to actively participate in the learning of mathematics (Meke, Jailani, Wutsqa, & Alfi, 2019). A student's interest in mathematics can affect their attitude about the subject (Degenhart et al., 2007). Gaining the interest of a student can help them become more successful (Rice et al., 2013). Students who have support when learning math increase their motivation and, in turn, increase their math test scores (Montrieux et al., 2016). Students who end up with math-related careers typically were interested in the subject at younger ages and likely ended up taking more math courses in secondary school (Harris et al., 2017). Also, it is crucial for teachers to understand that students are continuously changing how they feel about learning math. Kim and Ju (2012) determined students who participated in a geometry inquiry classroom, an experimental class that uses a student's inquiry to teach geometry and proofs, changed their attitudes about how they perceived themselves as learners of mathematics.

Prior Knowledge

A student's prior knowledge is important in helping them achieve success in any subject (Pressley et al., 1992). Providing students the opportunity to connect new knowledge to prior knowledge allows them to build their mathematical understanding (Brijlall et al., 2013). Teachers must take into account the fact that students do not always have the prior knowledge they need to construct proofs on their own (Weber, 2001), making a challenging concept even more difficult. Being able to identify what mathematical knowledge a student has can prove to be difficult, especially with geometry and writing proofs (Hill & Ball, 2004). If students are lacking in the prior knowledge needed in geometry, they will struggle to engage in logical thinking (Aminah et al., 2018). This can make it difficult to implement interventions to promote geometric learning. For example, Verzosa et al. (2018) found using technology for proofs may not work for students if they are lacking the prior knowledge they need to understand the proof process. The effectiveness of mathematics instruction will depend on what knowledge the student already possesses (Clarke et al., 2005).

Geometry Self-Efficacy

Self-efficacy is an individual's beliefs about their ability to successfully perform a specific task (Bandura, 1986). Mathematical self-efficacy is an individual's beliefs about their ability to successfully perform mathematical tasks (Hackett & Betz, 1989). Mathematics self-efficacy can accurately predict mathematics achievement (Recber et al., 2018).

Similarly, geometry self-efficacy reflects an individual's beliefs about their ability to successfully perform geometry tasks. There is a strong, positive correlation between a student's attitude toward geometry and their self-efficacy beliefs when learning the subject (Ünlü et al., 2010). Students with a positive attitude about geometry have a better chance at being successful in the course (Ünlü et al., 2010). Geometry achievement has an impact on geometry self-efficacy (Ünlü & Ertekin, 2017; Yüksel et al., 2013). Consequently, encouraging students to have a positive attitude about geometry can positively affect their geometry self-efficacy (Kundu & Ghose, 2016). Supporting students in a geometry course is imperative in their ability to build a strong, positive sense of self-efficacy with the subject.

Importance of Proofs

Proofs are an important part of a secondary school geometry course. Students need to understand what a proof is before they can realize why it is important to master proof writing (Selden & Selden, 2003; Yang & Lin, 2008). Proofs are truth statements about properties and their mathematical relationships, and they can be considered some of the building blocks of mathematics (Pier et al., 2019). Proofs are referred to as an argument proving a statement is true by deductive reasoning (Selden & Selden, 2003). Furthermore, proof writing entails a student's conjecture, followed by their logical statements to show the conjecture is true (Komatsu & Jones, 2019).

Proofs have a special significance in geometry. Proofs given in high school help teach students how to think logically and critically as well as how to justify the mathematical statements they make (Herbst & Brach, 2006). The two-column format of a proof is what is used in high school classrooms to determine whether or not a student understands how to prove a statement (Aaron & Herbst, 2019). In addition, two-column proofs can provide structure for a student when they are reasoning with mathematical relationships (Verzosa et al., 2018). Furthermore, a student's ability to write a two-column proof is determined by whether or not they can take given information; apply the appropriate geometric theorems, definitions, postulates, and properties; and reason deductively step by step down to the conclusion they are given in the proof (Wong et al., 2011). There is much emphasis placed on proofs and a student's ability to write a two-column proof in geometry. The ability for a student to be able to achieve success with even the simplest of proofs is important for the development of their critical and logical thought processes in mathematics.

Reading Comprehension in Proofs

Reading comprehension is a major component of mathematical proofs, as research shows there is a connection between proof comprehension and proof writing (Housman & Porter, 2003; Yang, 2012; Yang & Lin, 2008). Language is a problem for students when writing proofs in geometry, which makes it difficult for students to understand geometric proofs (Edwards & Ward, 2004; Inglis & Alcock, 2012; Robotti, 2012; Yang & Lin, 2008; Zazkis et al., 2016). There is a relationship between the way students read and comprehend proofs and the strategies they use to try to work through them (Housman & Porter, 2003; Yang, 2012). In order for students to be able to use strategies to read and comprehend proofs, students need to have language within a proof that is understandable (Otten et al., 2017; Robotti, 2012). Making sure students are able to comprehend what they are reading when they tackle proofs will help them become more successful at proof writing.

Mathematics Teaching

The teaching of mathematics plays a big role in K–12 mathematics education. This section addresses how the teacher can influence student achievement in mathematics. It includes a discussion of strategies teachers can use for teaching proof writing to students as well as ways teachers can implement different proof-solving techniques.

Teacher Influence

Teachers are in control of what and how students learn in the classroom (Aaron & Herbst, 2019; Gabel & Dreyfus, 2017). When teaching proofs, this is especially significant. Teachers can guide students when they are working on a proof in order to get a specific outcome (Aaron & Herbst, 2019). Teachers' attitudes can also dictate how students feel about certain aspects of math. Not all teachers believe teaching proofs in geometry is important (Knuth, 2002), which can leave a negative impact on students. Teachers' attitudes toward math and about how their students learn can influence whether students become anxious about learning math (Dowker et al., 2016; Olson & Stoehr, 2018). Teachers must remain aware of how their attitudes can affect students' learning (Aaron & Herbst, 2019).

Teachers' content knowledge can also affect their ability to help their students learn (Bleiler et al., 2014). A teacher's own knowledge, or lack thereof, will influence the instruction they provide (Swafford et al., 1997). Teachers need to be comfortable with proofs to effectively teach them to their students (Bleiler et al., 2014). In addition, enhancing a teacher's geometric knowledge will influence their students' learning of geometric concepts (Knuth, 2002; Swafford et al., 1997). Teachers' content knowledge and self-efficacy affect students' learning.

When using technology, teacher influence can have a huge impact. Teachers must believe the technology they are planning to use is beneficial for students; otherwise, students will not believe the technology is valuable (Knuth, 2002; Tatar et al., 2015). Teachers must also be comfortable with the technology they integrate into their classrooms (Knuth, 2002; Tatar et al., 2015). Increasing the computer literacy skills of math teachers can help decrease their own math anxiety, which better helps them instruct students with the technology (Tatar et al., 2015). In a quantitative study of ninth-graders, Mailizar and Johar (2021) found that teachers who were able to show their students the usefulness of a technology, had a better chance of students using it. If a teacher does not believe in a technology, the students will not see the benefit of using it; likewise, if a student sees a teacher is not comfortable with the technology, the student will not see the value of that technology (Knuth, 2002; Tatar et al., 2015).

Strategies for Proof-Writing

Teachers can use a variety of instructional strategies to help students learn proof writing (Herbst, 2002). Altering the flow of a proof can help determine what a student learns from the proof (Gabel & Dreyfus, 2017; Hahkioniemi, 2017; Weber, 2015). Students need to be engaged in the proof in order to be able to comprehend it (Ko & Knuth, 2009). Students need different ways to approach proofs in order to be successful proof writers (Gabel et al., 2017; Weber, 2001, 2015). For example, using apps that allow manipulations can help students develop their geometric understanding of proofs (Chang et al., 2014). Also, allowing students to explain their proofs with words and diagrams together can help them do better (Healy & Hoyles, 2000). Diagramming proofs is another way to make them clearer for students (Sinclair et al., 2016). In addition, using fill-in proofs can make learning proofs easier for students (McCrone & Martin, 2004). Students need to be able to validate their arguments in proofs (Selden & Selden, 2003), and giving them different options to do so is imperative for their understanding.

Being able to discuss proofs is a great strategy to use in geometry. Discussion is important for students when they are learning to write proofs (Chazan, 1993). Soto-Johnson and Fuller (2012) found that even though first-year college students were not able to write out full proofs, they could verbalize them. Allowing students to compare their answers can help them better understand how to write a proof (Weber, 2015). In fact, not discussing proofs that are incorrect can actually hurt a student's understanding of the geometric concept (Alcock & Weber, 2005). Discussing proofs within the classroom is an easy, yet constructive strategy to use when teaching students how to write proofs.

Implementing Proof-Solving Techniques

In addition to having specific strategies to use for proof writing, being able to implement proof-solving techniques is a crucial asset for a teacher. Two important proof-solving techniques are interactive proofs and visualization.

Interactive proofs have a positive impact on students' ability to learn proof writing. Teachers can use technology to help students approach proofs in different ways (Leikin & Grossman, 2013; Mejía-Ramos et al., 2017). Using technology for proofs can help teachers create better investigative problems for their students (Leikin & Grossman, 2013). In addition, Ruthven et al. (2008) found using technology offers students flexibility when they are trying to solve proofs. Making proofs interactive in a geometry class helps students become better proof writers.

Being able to correctly visualize what is happening within a proof is important for students. Students make many mistakes when producing correct diagrams for geometric arguments (Komatsu et al., 2017), which can keep them from deepening their understanding. Using visual representations, such as proof trees, can help low- and middle-achieving geometry students write proofs (Wong et al., 2011). Seeing diagrams and pictures helps support students' understanding of proofs (Komatsu et al., 2017). Introducing a visual aid, like a flow-chart proof, can help students visualize a proof, helping them to avoid a circular logical argument (Miyazaki, Fujita, & Jones, 2017). Students can take the visualization of a proof and use it to strengthen their understanding and become better proof writers.

Adaptive Web-Based Learning Environments

Adaptive web-based learning environments are more frequently being used throughout all levels of education (Kolb & Kolb, 2005). These environments provide a more personalized learning experience, making them enticing to students and teachers alike. Much research has been done about the effectiveness of these learning environments in all subjects and how they can best be applied to support students. This section addresses the individualized support provided by adaptive learning environments, how adaptive learning environments have been used in mathematics, and more specifically, how adaptive learning environments have been used in geometry.

Individualized Support

One of the main components of adaptive web-based learning environments is the fact that they provide individualized support for students. These environments adapt to the learner and provide information based on the learning needs and preferences of the user. Different personal traits can be addressed by these learning environments. It is necessary to look at how the learner is affected by an adaptive learning environment as well as how teachers can use adaptive learning environments to best support their students.

Personal Traits

The personal traits of the learner are the most used and applied within adaptive learning environments to give students a more self-directed learning experience (Normadhi et al., 2019). Additionally, adaptive learning environments can provide students a more personalized learning experience as opposed to just a learning action (Mavroudi et al., 2018). The adaptive learning environments take into account the way a student learns information. Adapting to the learning preferences of a student can help them better understand concepts (Alias, 2014). Being able to specify how a student learns best can help teachers prepare lessons and questions that help students deepen their understanding. It can also help each student understand how they learn best so they can adjust how they approach information.

Student Ability

A student's ability level can make it difficult for them to adapt to new methods of teaching and tools used in the classroom (Wadlington & Wadlington, 2010). Adaptive learning environments can benefit students because they use data that are specific to the learner in order to customize the learning experience (Khosravi et al., 2020). Adaptive learning environments can be beneficial to all students, whether they are low-ability, middle-ability, or high-ability. Low-achieving students benefit from using adaptive learning environments in math classrooms, especially when learning difficult concepts (Reinhold et al., 2019). Additionally, students with less prior knowledge can benefit from an adaptive learning environment (Flores et al., 2012). Furthermore, adaptive learning environments have been shown to have a positive impact on low achievers in mathematics (Khalil et al., 2019; Poon & Wong, 2017; Reinhold et al., 2019). It was determined that using a tutorial-based learning environment helped to close the gap between high and low ability geometry students (Ojimba, Gogo, & Chetachi, 2020). In addition, both high-motivated and low-motivated students can benefit from an adaptive learning environment (Flores et al., 2012). Having the immediate support from an adaptive learning environment can provide a positive learning experience for the student (Mavroudi et al., 2018). Knowing that students of all ability levels can be helped by adaptive learning environments makes them an asset to use in education.

Student Engagement

Student engagement in mathematics refers to a student's investment in and effort given towards understanding and mastering the content (Newmann, Wehlage, & Lamborn, 1992). Using information from five different projects throughout 94 different middle and high schools throughout the United States, Newmann et al. (1992) found that students worked harder when engaged in their learning. Yet, it is difficult for mathematics teachers to keep all students engaged all the time throughout their classes. Often times, students within the same class have differing levels of interest in the subject as well as different ability levels (Arroyo et al., 2014). Adaptive learning environments can help address this problem by providing students with reasonable goals as well as keeping students interested in the problems given to them, even when they cannot get personal attention from the teacher (Arroyo et al., 2014). Perry and Steck (2015) studied 110 geometry students and found integrating an iPad into the classroom increased overall student engagement. Additionally, Liu (2007) found using wireless technology in a middle school math classroom not only increased student engagement, it helped students focus more and make less errors. Faber et al. (2017) also found the immediate feedback students receive using an adaptive learning environment can help keep them motivated as they work through mathematical problems. Furthermore, a case study of 150 students found that students were more interested and engaged in their learning when they used web-based learning for their studies (Amos, Sharma, & John, 2020).

Student Perceptions of Using Adaptive Environments to Learn

Students can use adaptive learning environments to take control of their learning experience and better understand how they learn (Khosravi et al., 2020). It was determined that students widely accepted the use of an adaptive web-based learning environment within a mathematics classroom (Mailizar & Johar, 2021). There are numerous benefits for students in using adaptive web-based learning environments. When an adaptive web-based learning environment is easy for students to use, they are more likely to use it (Mailizar & Johar, 2021). Students have reported an adaptive learning environment in the form of a tutoring system helped them progress further because they received immediate feedback on their work (Vesin et al., 2018). Furthermore, students' attitudes are positively affected when they see the usefulness of a technology (Mailizar & Johar, 2021). In addition, students like being able to visualize with adaptive learning environments as well as the ability to compare their answers with others (Vesin et al., 2018). The ability of a student to have the benefits of a personalized learning experience makes adaptive learning environments an advantage to have and use in the classroom. When used to supplement instruction, adaptive web-based learning environments can have a positive impact on students (Mailizar & Johar, 2021).

Teacher Support

With crowded classrooms and many students needing teacher attention, it is difficult for students to receive the individualized support they need in a mathematics classroom. Adaptive learning environments can be an aid for teachers in giving students the personalized attention they need (Walkington & Sherman, 2012) because students can be working at different levels at the same time while getting immediate feedback. An adaptive learning environment can also be used as a scaffolding tool in helping teachers as they work to address the needs of all students (Khalil et al., 2019). If teachers use adaptive learning environments as supplements to their curriculum, they can improve their students' learning with minimal effort on everyone's part (Gebhardt, 2018). Teachers can use adaptive learning environments to get a better idea of how each of their students learn, and, in turn, alter their teaching styles to better reach each student (Hamada & Hassan, 2017). Adaptive web-based learning environments can be a great tool for educators to use to create individualized learning experiences for students.

Adaptive Learning Environments in Mathematics

Adaptive learning environments can be useful in a mathematics classroom. The following sections address certain steps teachers can take to get the most out of using adaptive learning environments in their curriculum. In addition, this section covers blending teacher-led instruction with adaptive web-based learning environments, as well as the positive effect adaptive learning environments can have on a student's ability to learn mathematical concepts.

Role of the Educator

Teachers must believe in what they are using in order for it to have a positive effect on their curriculum and their students. Teachers need to be ready to implement an adaptive learning environment into their mathematics curriculum in order for it to be effective; if they are not ready, they may view using such an environment as more of a detriment to students (Phillips et al., 2020). It is also important for teachers to make sure their students are paying attention to the adaptive learning environment being used within the curriculum (Phillips et al., 2020). According to Nye et al. (2018), teachers must help students remain on task in order for them to get the most out of adaptive learning environments in their math classes. Students may miss the positive effects of an adaptive learning environment if they do not have their full attention on it (Phillips et al., 2020).

Effect on Students

Adaptive learning environments can have a positive effect on students. Using adaptive learning environments can help students better develop their mathematical skills (Phillips et al., 2020). There are learning environments that are designed specifically for mathematics courses, such as GeoGebra, Geometer's Sketchpad, Cabri, and ALEKS. Access to these mathematical adaptive learning environments has been shown to help students better comprehend mathematical concepts (Ozyurt et al., 2013). Using these adaptive learning environments in a mathematics class can help students learn better because they can adapt to each student's personal learning style (Nye et al., 2018). Even though the effects are positive for students who use these environments in their math classes, the students must have the necessary technological knowledge to gain the full benefit (Hollebrands et al., 2010).

Blending Technology with Instruction

Recent studies have found that blending face-to-face instruction with adaptive web-based learning environments is the most effective way to have positive results for students. Ojimba, Gogo, and Chetachi (2020) conducted a quasi-experimental research study with 6,589 high school students and found that students learned better overall with a blend of teacher-led instruction and the use of an adaptive web-based learning environment. Similarly, the results of a study of 241 junior high students showed that blending teacher instruction with technology was most effective for helping students develop their problem-solving skills (Lin et al., 2020). Additionally, Amos, Sharma, and John (2020) found that students utilizing adaptive web-based learning environments within a classroom were more likely to utilize the available learning resources. In addition, a research study involving 236 high school students discovered that using technologies in conjunction with regular instruction helped students improve their self-efficacy and motivation to learn, as well as increase their confidence by gradually increasing the difficulty level of the questions, a main aspect of adaptive web-based learning environments (Gu & Lee, 2019).

Adaptive Learning Environments in Geometry

Adaptive learning environments have been used for a variety of concepts within geometry classrooms. It is important to address how educators have used adaptive learning environments within their geometry classrooms as well as the impacts. Additionally, it is important to discuss what students can gain from having used adaptive learning environments when learning geometric concepts. The following sections address both of these areas.

Using Adaptive Learning Environments in the Classroom

Dynamic geometry environments have been and continue to be a major factor in geometry classrooms and curricula. One of the main reasons for this is because a dynamic geometry environment can help teachers create investigative problems and better understand how to help their students (Leikin & Grossman, 2013). The personalized nature of the dynamic software allows for this to happen. For example, Hahkioniemi (2017) found that using the dynamic geometry software, GeoGebra, in the classroom helped teachers ask better questions of their students.

Although using dynamic geometry environments can be beneficial, teachers must use caution when using them. This is important because students tend to trust any answers given to them by a device, regardless of whether it is the correct answer or not (Koyuncu et al., 2015). Though technology can help students use alternative strategies when solving geometry problems, it is still a good idea to use technology together with pencil and paper (Hadas et al., 2000).

Impact on the Student

The impact on the individual student also plays a role when using a dynamic geometry environment within the classroom. A dynamic geometry environment helps students understand logic, which allows them to develop more meaningful solutions and helps them to gain deeper geometric insight (Koyuncu et al., 2015). Using dynamic geometry software has been found to help students make better geometric connections (Komatsu & Jones, 2019). For example, Bhagat and Chang (2015) found that using GeoGebra in the classroom motivated ninth-grade students and, in turn, helped them better learn geometric concepts. Additionally, dynamic geometry environments can help students become better at explaining geometric concepts (Hadas et al., 2000). Major goals of geometry are for students to be able to use logic, make connections, and explain their thoughts and how concepts are related. Research has shown dynamic geometry environments can help students with all of these processes.

Dynamic geometry environments also have an effect on students when writing proofs. Using technology in an inquiry-based classroom can help motivate students and increase their ability to perform proofs (Segal et al., 2018). Students can also use a dynamic geometry environment to explore proofs before having to make any justifications, which can help them understand the need for abstractness with justification in proofs (Marrades & Gutierrez, 2000). Gardiner et al. (2000) found that using hand-held technology can promote the development of student understanding of proofs. Wang and Su (2015) also discovered that using iGeoTutor helped students learn proofs. The positive results of students doing proofs in geometry when using dynamic geometry environments are important to keep in mind when working through geometry curricula.

Student ability is also an important factor to consider when looking at whether to use a dynamic geometry environment in the classroom. Technology can make a difference in student interest and how well a student performs in geometry (Idris, 2007). Regardless of ability level, dynamic geometry environments can be a positive experience for students. Khalil et al. (2019) found that using GeoGeobra in a geometry classroom can have a positive effect on both high and low achievers. Furthermore, using preconstructed dynamic geometry environment materials can help low-achieving students visualize geometric concepts (Poon & Wong, 2017).

Conversely, dynamic geometry environments cannot be expected to solve all problems within the geometry classroom (Albaladejo et al., 2015). Though some dynamic geometry environments helped students with the visualization of concepts, they did not help with students' abilities to reason (Albaladejo et al., 2015).

Chapter Summary

The focus of this literature review was on adaptive web-based learning environments and K–12 mathematics education. The first section covered K–12 mathematics education and included mathematical struggles for students, student mathematical achievement, and challenges for mathematics teachers. It addressed strategies that have been used and their impacts in terms of student knowledge in geometry and two-column proof writing. It also addressed how mathematics teachers have been involved in the process of student proof writing with regard to student mathematics achievement and adaptive web-based learning environments.

The second section addressed web-based learning environments. It included how web-based learning environments have been used in education as well as how they have been used in mathematics education, specifically geometry. It addressed the impact of web-based learning environments on mathematics achievement as well as geometry achievement.

Many adaptive web-based learning environments have been used in geometry classrooms to help promote student understanding of geometric concepts; however, there is a lack of research on these environments and their impact specifically in the area of proofs. The aim of this research study was to implement and evaluate the effectiveness of personalized geometry instruction and practice through an adaptive web-based learning environment for high school geometry students.

CHAPTER 3

METHODOLOGY

The purpose of this action research study was to implement personalized geometry instruction and practice through an adaptive web-based learning environment for high school geometry students at a private school in North Carolina and evaluate its effectiveness. The following are the three research questions that guided this study:

1. How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry?
2. How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept?
3. What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry?

Research Design

In this study, I used a mixed methods action research design to examine the effects of using an adaptive web-based learning environment for geometry instruction and practice on high school students' geometry problem solving. This enabled me to determine whether using an adaptive web-based learning environment had an effect on students' ability to learn geometry. Mertler (2017) stated action research is,

> any systematic inquiry conducted by teachers, administrators, counselors, or others with a vested interest in the teaching and learning process or environment for the purpose of gathering information about how their particular schools operate, how they teach, and how their students learn. (p. 4)

Action research is what allows a teacher to look at what is going on within their classroom and try to improve on their practices. Action research can lead to change within a teacher's instructional practices (Brydon-Miller et al., 2003). I used the results from this study to inform my own practice and help identify problem areas.

Traditional research involves an outsider studying something, whereas action research involves an insider studying something close and familiar to their practice. Action research tends to produce more valid results than traditional research because the local stakeholders are involved (Brydon-Miller et al., 2003). In action research, the researcher can use the data they find and make changes to improve upon their classroom, district, instructional methods, or other areas. In traditional research, the researcher can discuss their data and any trends they find, but they do not have the ability to change anything because they are not studying their own school or their own classroom (Mertler, 2017). There are four steps involved in action research: identifying a focus area, collecting data, analyzing and interpreting the data, and coming up with an action plan (Mertler, 2017).

There are several reasons why action research was appropriate for my study. First, this process helped me identify the areas in my own teaching practice in need of improvement. In addition, I gained a better understanding of how to use an adaptive web-based learning environment within my classroom. Furthermore, action research allowed me to gain a better understanding of how changing my teaching practices can influence my students' learning of geometry.

When looking at what type of research to perform, one can find pros and cons for both qualitative and quantitative research. Each type of research has both strengths and limitations. When a researcher pulls from the good qualities of each and performs a study that incorporates both qualitative and quantitative research, it is deemed mixed methods research. Merging qualitative and quantitative methods together can give a deeper understanding of the issue being studied (Creswell, 2014). It may also be appropriate to use mixed methods when the research questions dictate that both qualitative and quantitative data are necessary (Mills, 2014).

Mixed methods research has been used frequently throughout mathematics education to enhance the findings from both qualitative and quantitative data sources (Ross & Onwuegbuzie, 2012). For my research, I used a convergent parallel mixed methods design. In this type of mixed methods design, the researcher performs the qualitative and quantitative data collection separately and then merges the results together as the data are being analyzed (Creswell & Plano Clark, 2018; Schoonenboom & Johnson, 2017). Using this type of mixed methods research, I collected both qualitative data and quantitative data at the same time throughout my study. I then analyzed each of them separately from one another and compared and contrasted the results. I looked for themes supported by both the qualitative and quantitative data and determined whether any of the data were contradictory. The qualitative and quantitative data should supplement each other, confirming the data collected and making the analysis and interpretation stronger (Rudestam & Newton, 2007).

Using both qualitative and quantitative methods provides a better understanding of the problem underlying the research than either of the methods singularly (Creswell, 2014). I used interviews to gather qualitative data and a content knowledge pre- and post-assessment as well as questionnaires to gather quantitative data. The participants were the same for both the qualitative data collection and the quantitative data collection. The combination of both qualitative and quantitative data gave my research data more depth and allowed for stronger results.

Setting and Participants

Because this was an action research study, I conducted my research as a participant researcher within the classes I taught. The participants were students in my regular-level geometry classes. This was the lowest level of geometry offered at the chosen school. Geometry is a course focused on exploring relationships, such as congruence and similarity, while strengthening algebra skills through geometric modeling properties. Students are taught to approach problems with a specific goal in mind in order to logically develop appropriate steps to reach their conclusion. All students who participated had completed a prerequisite algebra course but had limited exposure to geometry and geometric concepts.

A total of 44 student participants took the content knowledge pre- and post-assessments. Table 3.1 illustrates the demographic information for all of the participants. Students were 82% (n = 36) Caucasian, 11% (n = 5) African American, and 7% (n = 3) Latin American. Of the total participants, 52% (n = 23) were male and 48% (n = 21) were female, and 25% (n = 11) were in Grade 9 and 75% (n = 33) were in Grade 10. In addition, eight students indicated they had used an adaptive web-based learning environment in a previous mathematics course.

Table 3.1 *Demographics of Participants: Ethnicity, Gender, Grade Level (n = 44)*

Demographic characteristic	Frequency	Percentage
Ethnicity		
Caucasian	36	82%
African American	5	11%
Latin American	3	7%
Gender		
Male	23	52%
Female	21	48%
Grade level		
9th	11	25%
10th	33	75%

The research took place on a campus of almost 45 acres with 15 buildings spread throughout. The classroom used for this research was an adaptive learning space with flexible seating that enabled me to configure the classroom as I needed depending on the lesson. There were white boards covering the two side walls, windows on the entire back side, and a glass wall at the front of the classroom. There was an interactive Smart Board at the front of the classroom. This allowed both myself and the students to connect and show work from iPads.

At the beginning of the intervention, the student desks were arranged six feet apart throughout the classroom to comply with social distancing guidelines. In addition, each student desk was surrounded by plexiglass on three sides. Students were able to work on their personalized geometry practice throughout the class while having access to the whiteboards on the sides of the room in order to work out problems as needed. They also had access to Expo markers to work out problems on the plexiglass at their individual desks. By the end of the intervention, students were seated near classmates three feet apart and could collaborate if necessary. I was able to monitor the class and their progress by walking around the perimeter of the classroom. Classes had an average of 15 students.

Each class met for 60 minutes every two out of three days on a rotating schedule for the entire semester. During each class period, I began by reviewing the previous lesson and answering questions about homework. I introduced new content, which was followed by either individual practice or collaborative practice. Part of the individual practice was the intervention. At the end of each class period, we reviewed any questions and what was expected to be completed for the following day.

I introduced the intervention of a web-based adaptive learning environment over a 7-week period. Students are issued iPads in the fourth grade and keep them for 3 to 5 years, at which time they are switched out for newer versions. All of the participants had received new iPads within 1 to 2 years of taking my geometry class and used these school-issued iPads for the intervention. Participants had the iPads to use in the classroom on a daily basis, and they also had them at home.

The 44 students who participated in the research were a mixture of students in Grades 9 and 10. I chose to use a purposeful sampling method because I was specifically focusing on my own students (Etikan et al., 2016; Levine, 2014). There was a total of four regular geometry classes being taught at the school. I chose the student participants based on their enrollment in the three geometry classes I taught. Students were randomly assigned to their classes, so this provided a random sampling of students taking geometry and helped create a group of participants who varied in terms of level of ability. I randomly assigned numbers to my students to keep their identities anonymous throughout the entire research process (Mertler, 2017).

Intervention

In this study, I used an adaptive web-based learning environment to support personalized geometry instruction and practice. The following is a description of the adaptive web-based learning environment and how it was used in this study.

Adaptive Web-Based Learning Environment

Teachers use adaptive web-based learning environments to provide personalized instruction to students through self-directed work (Normadhi et al., 2019; Ozyurt et al., 2013). These systems can be beneficial for teachers and students because they provide immediate individualized feedback to students and adapt to their ability level and skill set. Research has shown adaptive learning systems can help students in mathematics (Phillips et al., 2020). Using an adaptive web-based learning environment can aid teachers in helping students while they learn and practice their mathematical skills.

I chose to use the IXL web-based adaptive learning system, which adapts the question difficulty according to the knowledge level of each individual student. Students are highly unlikely to see the same question twice because the problems are algorithmically generated. This gives students the opportunity to have a limitless supply of practice.

IXL personalizes the learning experience for each student by using their previous answers to questions as well as real-time information, such as how long it takes to answer a specific question. The questions on a specific skill get more difficult as students continue to answer correctly. If a student answers incorrectly, they are offered guidance and support. The questions build on what the student has already mastered. Table 3.2 shows how IXL addresses specific student problems.

Table 3.2 *IXL and How it Addresses Student Problems*

Problem	How IXL addresses the problem
Student motivation	• Provides positive feedback to students when answers are correct • Offers explanations when students make errors • Keeps low-achieving students encouraged to continue working on problems by providing information • Provides virtual awards for concepts mastered that can be individualized to each student
Lack of individualized attention	• Provides individualized and personal feedback to students as they answer questions • Aids the teacher in the scaffolding process
Student engagement	• Provides goals for students to work toward • Keeps students working on problems even when the teacher cannot provide individualized attention by offering help and explanations • Allows students to create a digital portfolio of their progress
Geometry self-efficacy	• Helps foster positive attitudes by encouraging students both when they are correct and incorrect • Allows students to work at their own level and their own pace by giving questions tailored to each student's level • Gives students the chance to progress according to their own individual needs
Student struggles in mathematics	• Offers explanations when students do not understand a problem • Gives students extra practice • Allows students to work on different concepts at different times so they can work on building their confidence in areas where they have a better understanding

Implementation

I supported my geometry instruction by integrating IXL into my teaching. The implementation took place over a 7-week period and covered two different units in geometry: quadrilaterals and similar triangles. The adaptive learning system supported my instruction and was a supplemental piece as I went through the units. I used it for individualized practice for students both in and out of the classroom. I targeted the following North Carolina state content standards during this intervention:

- G.CO.11 – Prove theorems about parallelograms.
- G.MG.3 – Apply geometric methods to solve problems.
- G.SRT.2 – Give two figures, use the definition of similarity in terms of similarity transformations to decide if they are similar; explain using similarity transformations the meaning of similarity for triangles as the equality of all corresponding pairs of angles and the proportionality of all corresponding pairs of sides.
- G.SRT.3 – Use the properties of similarity to establish the AA, SAS, and SSS criterion for two triangles to be similar.
- G.SRT.4 – Prove theorems about similarity.
- G.SRT.5 – Use congruence and similarity for triangles to solve problems and to prove relationships in geometric figures.

During the intervention, each instructional unit took 3.5 weeks to complete. I gave students two assignments from IXL per week. The first two weeks of each unit consisted of two in-class assignments and the remaining weeks of each instructional unit consisted of one in-class assignment and one outside homework assignment. The in-class assignments took 30 minutes each and the homework assignments took 20 minutes each. A total of twelve, 30-minute in-class assignments and four, 20-minute homework assignments were completed by students during the intervention.

After the content knowledge pre-assessment and initial questionnaires had been conducted, instruction on quadrilaterals took place. All standard instruction practices took place as normal, but assignments were given from IXL to supplement student practice. In week one, students were given instruction on three different concepts and were given two in-class assignments from IXL to complete. The 30-minute assignments consisted of practicing parallelograms and proving quadrilaterals are parallelograms. This practice was completed during normal class periods.

In week two, students were given instruction on three new concepts and were given two in-class assignments to complete from IXL. They had to practice rectangles for 30 minutes and practice rhombi/squares for 30 minutes. Both of these assignments took place during a normal class period. To conclude the unit in the remaining weeks, students were given two additional 30-minute in-class assignments from IXL as well as two 20-minute homework assignments from IXL that were completed outside of class. These assignments were practice on trapezoids and kites as well as practice on all quadrilaterals.

The rest of week four began the new instructional unit on similar triangles. Students were given instruction on two new concepts and were assigned two in-class assignments from IXL. They had to practice angle-angle similarity for a 30-minute time period for the first assignment. The second assignment consisted of practicing side-angle-side similarity and side-side-side similarity for a 30-minute time period. Both of these assignments took place during a normal class period.

At the end of week five of the implementation, students were given another two in-class assignments from IXL. The first assignment required students to practice similar triangle proofs for 30 minutes. The second assignment required students to practice proportional parts of triangles for 30 minutes. Both of these in-class assignments took place during the normal class period.

The final weeks of the implementation were a review of similar triangles and writing proofs. There were two additional 30-minute in-class IXL assignments given to students as well as two 20-minute homework assignments from IXL that were completed outside of class. The in-class assignments required students to complete similar triangle proofs. The homework assignments were a review on all parts of similar triangles that were covered throughout the unit. This was followed by the final phase of the research study.

Data Collection

This study was guided by a mixed methods approach. The quantitative data and qualitative data included student interviews, student self-efficacy questionnaires, and a content knowledge pre- and post-assessment. Students in all three of my classes received the intervention. I obtained site approval (see Appendix A) and IRB approval (see Appendix B) before data collection began. Table 3.3 provides the alignment between the research questions and the data collection methods.

Student Interviews

Using interviews as a form of data collection in my research study enabled me to clarify answers given and to ask questions for more detail when needed, as well as to record the interviews and preserve the data I collected (Mertler, 2017). Although interviews can be time consuming, they can provide useful data (Mertler, 2017). Interviewing students also allowed students to explain their answers, something that may not have been easy for them to do with just a questionnaire or a test. I created the

Table 3.3 *Research Questions and Data Sources Alignment*

Research question	Data collection methods
RQ1 - How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry?	• Content Knowledge Pre- and Post-Assessment
RQ2 - How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept?	• Motivation Questionnaire • Self-Beliefs Scale • Student interviews
RQ3 - What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry?	• Student interviews

interview questions from scratch using the research questions as a guide. Yes and no questions were turned into open-ended questions wherever possible in order to provide more thick, rich description.

I conducted a total of 15 student interviews that were recorded and transcribed so they could be analyzed after the fact. The interviews (see Appendix C) were semi-structured and designed to gather information about the perceptions and experiences of the participating students (Creswell, 2014) with regard to using an adaptive web-based learning environment for geometry.

I chose the students for the interviews based on their questionnaire responses, pre-assessment scores, and amount of time spent on the intervention throughout the research. I chose three students who scored very low on the content knowledge pre-assessment and three students who scored very high. I then chose two students with low questionnaire scores and two students with high questionnaire scores. Finally, I chose three students who spent a lot of time using the intervention and two students who spent the minimum amount of time using the intervention. If one of the students declined to participate in the interview process, I chose a student with similarities in terms of score or amount of time used. I interviewed the students individually after the implementation of the intervention, after the content knowledge post-assessment had taken place, and after the final questionnaire had been administered.

The interviews lasted 10 to 20 minutes and took place before school, during lunch, and after school. The interview questions focused on student perceptions about geometry, their mathematics self-beliefs and motivation, and their experiences with mathematics self-efficacy, anxiety, self-concept, motivation, using technology as a tool in a mathematics class, and how they felt the intervention did or did not play a role in their possible improvement. Students were asked to explain all of the answers they gave and were allowed time to elaborate wherever they felt necessary. Table 3.4 shows the alignment of the interview questions to the research questions.

Self-Beliefs Scale

I measured students' geometry self-efficacy, mathematics anxiety, and mathematics self-concept using the Self-Beliefs Scale (Stankov et al., 2012). This questionnaire (see Appendix D) was designed to assess the self-efficacy, self-concept, and anxiety of students in the subjects of English and mathematics. For the purpose of this study, I only used the first three subsets and the mathematics questions. The scores for the mathematics anxiety subscale were reverse coded. Students responded to items such as "I get very nervous answering mathematics questions" on a 5-point Likert scale from 1 (*never*) to 5 (*always*). Previous reliability scores for the subscales of this instrument were reported as .91 for mathematics self-efficacy, .84 for mathematics

Table 3.4 *Student Interview Alignment*

Research question	Interview question alignment
RQ2 - How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept?	1. In general, what are your thoughts about math? About geometry? 1a. Would you say you struggle a lot? If so, how long has this been the case? 2. What have you used to help yourself learn geometry concepts? 2a. Have you ever thought about using technology as a tool to help you learn geometry? In what way(s)? 3. How do you think using IXL changed your motivation for learning geometry? 3a. Can you give me an example for a time when you felt engaged with solving problems in IXL? 3b. What aspects of this example made you feel that way? 4. How did using IXL affect your confidence in your ability to learn geometry? 4a. Can you give an example for a situation when you felt that you accomplished something you thought was very difficult to learn initially? 5. How did using IXL change your anxiety about solving geometry problems? 5a. Can you give an example of a time when you felt your feelings about solving problems in IXL change? 6. How do you think your ability to learn difficult concepts is now that you have used IXL? 6a. Can you give an example where solving a problem in IXL became easier than what you thought it would be?

Research question	Interview question alignment
RQ3 - What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry?	1. Are you used to using technology for your math classes? 1a. Can you give examples of how you have used technology in your math classes? 2. What are your thoughts about using a website for a math class, specifically geometry? 2a. Did your thoughts about using a website for a math class change after using IXL? Why do you think this is? 2b. What do you think some of the benefits could be? 2c. Is there anything that might be difficult about it? 3. Were you open to using technology to help you solve problems in geometry? Why or why not? 3a. How did you think you might be able to benefit from IXL in regards to learning geometry? 4. Describe the process you went through when working through the assignments you were given on IXL. 4a. How did your attitude about using IXL change from the beginning of the implementation to the end? 4b. Can you give an example of a problem you worked on where you felt your attitude shift? 5. Explain how you think using IXL did or did not help you improve your problem-solving ability in geometry.

Research question	Interview question alignment
	5a. Can you give an example where you solved a problem you didn’t think you would be able to initially? 6. Would this be something you think would be useful in the future? Why or why not? 6a. Comparing your thoughts before using IXL and after, would you sign up for another geometry class for next year?

anxiety, and .89 for mathematics self-concept (Stankov et al., 2012).

Motivation Questionnaire

I measured students’ motivation using the Science Motivation Questionnaire (Glynn, 2009). This questionnaire (see Appendix E) was designed to provide educators and researchers with student motivation information with regard to learning science. For the purpose of my research, I changed all instances of “science” within the questions to “geometry” and I eliminated the career motivation subscale. In addition, I eliminated two of the questions that were unrelated to this research study. A full list of the adaptations from the Science Motivation Questionnaire can be found in Appendix F. The motivation subscale used combined intrinsic and extrinsic motivation, totaling eight items, and the remaining four subscales of relevance to personal goals, self-determination, self-efficacy, and anxiety each contained five items. The anxiety subscale items were reverse coded. Students responded to items such as “Earning a good geometry grade is important to me” on a 5-point Likert scale from 1 (*never*) to 5 (*always*). A previous reliability score for the subscale of this instrument was reported as .93 (Glynn, 2009).

Content Knowledge Pre- and Post-Assessment

I used the content knowledge pre- and post-assessments (see Appendix G) to assess students' knowledge of quadrilaterals and similar triangles. This type of data collection provides a researcher with an idea of whether or not a change has occurred (Mertler, 2017). For this research, the content knowledge pre- and post-assessments were a pencil and paper test designed to evaluate students' content knowledge. They were given to students through Google Classroom and students completed them on their school-issued iPads.

The test covered two different units (i.e., quadrilaterals and similar triangles) and consisted of 30 total questions, 15 from each unit. The questions contained information about the concepts students were taught throughout the units. All of the questions were open-ended and required students to work out the problems and provide their own answer. There was one fill-in-the-blank two-column proof for the first unit on quadrilaterals. The remaining questions were a combination of algebraic problems and justifying statements. For example, one question gave students information about similar triangles and asked them to solve for the missing side or angle. Other questions asked students to justify whether or not a quadrilateral was a parallelogram or whether two triangles were similar.

The points awarded for each question ranged from 2 to 5 points, for a possible total of 100 points. Fifty points came from the unit on quadrilaterals and 50 points came from the unit on similar triangles. Because the questions were open-ended, students were able to earn partial points for some answers. I graded the content knowledge pre- and post-assessments with another geometry teacher (see Appendix H for rubric). The content knowledge pre-assessment was given before the intervention was introduced and the content knowledge post-assessment was given immediately following the completion of each unit during the implementation of the intervention. The geometry test created for the content knowledge pre-and post-assessments was created by me and graded with a colleague reviewed for content validity.

Data Analysis

Because merging qualitative and quantitative methods can give a deeper understanding of the issue being studied (Creswell, 2014), I used a convergent parallel mixed methods design for my research. In this type of mixed methods research, I collected both qualitative and quantitative data at the same time. I then analyzed each type of data separately and compared and contrasted the results. I looked for themes supported by both types of data and looked to see whether any of the data were contradictory. I used student interviews to gather qualitative data and used questionnaires and a content knowledge pre- and post-assessment to collect quantitative data. Table 3.5 shows the alignment of the research questions, data sources, and data analysis methods.

Quantitative Data Analysis

I collected the quantitative data from a content knowledge pre- and post-assessment as well as student questionnaires. I used descriptive statistics and paired sample t tests to analyze the data.

Content Knowledge Pre- and Post-Assessment

The content knowledge pre- and post-assessment was a quantitative form of data collection. The assessment was open-ended and divided into two sections, one for each instructional unit, that were each worth 50 points for a total of 100 possible points. I

Table 3.5 *Research Questions, Data Sources, and Data Analysis Methods Alignment*

Research questions	Data collection methods	Data analysis methods
RQ1 - How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry?	• Content Knowledge Pre- and Post-Assessment	• Descriptive statistics • Paired sample *t* test
RQ2 - How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept?	• Motivation Questionnaire • Self-Beliefs Scale • Student interviews	• Descriptive statistics • Wilcoxon signed-rank test • Inductive/thematic analysis
RQ3 - What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry?	• Student interviews	• Inductive / thematic analysis

graded the assessment according to a predetermined rubric. I used a dependent *t* test, with the significance value, to compare and contrast the participating students' scores on the pre-assessment with their scores on the post-assessment. I used the JASP computer program to gather descriptive statistics, including the mean and standard deviation and organized this information in tables and figures, as needed.

Self-Beliefs Scale

I used this questionnaire to collect quantitative data. This scale uses a 5-point Likert scale, which enabled me to use descriptive statistics when analyzing the results. I used the mean and standard deviation in addition to the Wilcoxon signed-rank test due to non-parametric data distribution.

Motivation Questionnaire

A second questionnaire used to collect quantitative data was the Science Motivation Questionnaire, adapted for mathematics. This questionnaire also uses a 5-point Likert scale, which allowed me to use the descriptive statistics of the mean and standard deviation. A paired sample *t* test was also planned for data analysis; however, the non-normal data distribution led to the use of a Wilcoxon signed-rank test.

Qualitative Data Analysis

I conducted student interviews to gather qualitative data. Using interviews as a form of data collection in this study allowed me to clarify answers given and to ask questions for more detail when needed, as well as to record the interviews and preserve the data collected (Mertler, 2017). Each of the interviews were recorded and transcribed so they could be analyzed. I used the interview transcriptions to organize the data, create codes for the text, and develop themes.

I used open coding for the first cycle of coding, allowing for an open-ended approach and engagement in other methods of coding throughout the process (Saldaña, 2016). During this first cycle coding, I employed simultaneous coding and in vivo coding. I completed two separate rounds of pattern coding for the second cycle coding in order to organize the vast number of codes created from first cycle coding (Saldaña, 2016). This allowed for the organization of the codes into more meaningful categories and for the identification of codes that might be specific to the research questions (Saldaña, 2016). After peer debriefing, I narrowed the data down into three themes and presented this information as a descriptive text (Saldaña, 2016).

Procedures and Timeline

This study took place during the spring of 2021. The procedures for this study were divided into four phases. Table 3.6 summarizes the timeline used for the procedures.

Phase I involved selecting and identifying participants. I notified students and parents of the research topic, purpose of the research, and the process that would be used for the research. I notified parents via email and spent the first week answering any questions. I then administered the Self-Belief Scale and the Motivation Questionnaire during a regular class period, and it took students 15 minutes to complete the measures. I then administered the content knowledge pre-assessment during one full 60-minute class period. One week was allowed for Phase I.

The intervention took place during Phase II. I introduced the intervention at the beginning of the first new instructional unit for students. I used 1 day to demonstrate how the technology worked and how students were expected to use it throughout the unit. Instruction continued as normal for the students. I used the intervention as a supplemental tool throughout the instructional unit. I gave students assignments in and out of class where the intervention was used. Students also participated in other methods of assignments that had been used throughout the school year. I encouraged students to use the intervention for extra help when struggling with geometry concepts throughout the unit. I conducted two instructional units throughout this research and gave a content knowledge pre- and post-assessment for each of the units. I gave students the post-assessment after each corresponding instructional unit had been completed. The first one occurred about 3.5 weeks after the intervention had been introduced and the second one occurred about 7 weeks after the intervention had been introduced. Each of the post-

Table 3.6 *Timeline for Procedures*

Phase	Researcher action	Participant action	Time frame
Phase I	• Select and identify participants. • Administer student questionnaires and content knowledge pre-assessment.	• Participate in student questionnaires. • Participate in content knowledge pre-assessment.	1 week
Phase II	• Perform descriptive statistics to gather initial quantitative data. • Select possible participants for student interviews. • Introduce intervention. • Provide assignments in and out of class using intervention. • Encourage use of intervention throughout units. • Administer each content knowledge post-assessment after the end of the corresponding unit. • Finalize participants to interview.	• Complete all assignments with intervention. • Participate in both content knowledge post-assessments.	7 weeks
Phase III	• Administer student questionnaires. • Conduct student interviews.	• Participate in student questionnaires • Select students participate in student interviews.	2 weeks
Phase IV	• Gather any descriptive data from intervention website. • Perform descriptive statistics to gather quantitative data. • Transcribe and code student interviews.	• Answer any necessary follow-up questions.	14 weeks

assessments took a full 60-minute class period. During this phase, I used descriptive statistics to gather quantitative data. I also finalized the selection of students who were to be interviewed based on their questionnaire responses, pre-assessment scores, and amount of time spent using the intervention. Seven weeks were allowed for Phase II.

In Phase III, I administered the Self-Belief Scale and the Motivation Questionnaire at the beginning of one class period. The measures took the students 15 minutes to complete. I also scheduled and conducted 15 student interviews. Phase III took place over a 2-week period.

In Phase IV, I collected descriptive data from student questionnaires, transcribed the 15 student interviews, and circled back with any information that needed to be further clarified. I coded the interview data and analyzed the descriptive statistics. This phase took place over a 14-week period of time.

Rigor and Trustworthiness

Throughout this research, I used a mixed methods design and gathered both quantitative and qualitative data. I conducted semi-structured interviews with 15 student participants. In conducting these qualitative methods of research, it was important to show that rigor and trustworthiness had been accounted for. In order to accomplish this, I used triangulation, peer debriefing, member checking, and thick, rich description.

Triangulation

Triangulation involves looking at different evidence from all of the sources of data and using it to create justifications for any themes (Creswell, 2014). I used method triangulation, which involved using different types of methods for the data collection. This helped me validate the conclusions derived through the data analysis (Olsen, 2004). I conducted the methods and collected data from both quantitative and qualitative methods at roughly the same time throughout the research, emphasizing each method as equally as possible (Mertler, 2017).

Triangulation provided data that helped explain certain themes that emerged and helped me to see things from a different perspective. Using different methods of data collection provided me a clearer picture of the results, producing validity (Torrance, 2012). It helped to aid in the credibility of the overall findings (Mertler, 2017). Using triangulation helped make my data appear less like a one-sided opinion and more like a valid and credible analysis derived from many different data collection methods (Johnson & Onwuegbuzie, 2004).

Peer Debriefing

Peer debriefing is the act of using another person or people to review a research study to make sure the results connect with people other than the researcher (Creswell, 2014). A person who helps with peer debriefing will ask questions and critique the research process as well as the data collected and how they were analyzed and interpreted (Mertler, 2017). The research chair aided in peer debriefing, as did a colleague who taught the same geometry classes. Those who aided in the process of peer debriefing provided insights and critiques that helped me stay on track and unbiased (Guba, 1981). Peer debriefing was crucial because it helped me ensure the data had been collected, analyzed, and interpreted honestly. It also helped to give the research credibility. Peer debriefing provided alternative perspectives and the ability to discuss different possible approaches to the data analysis, as well as insights about any errors that might have been present (Shenton, 2004).

Member Checking

Member checking is an extremely important action to take in research because it provides credibility (Guba, 1981). Member checking allows the participants to look at the transcriptions and researcher notes to ensure nothing has been misinterpreted or misunderstood (Mertler, 2017). Trustworthiness and fairness are promoted when member checking is used in research (Onwuegbuzie et al., 2010). It was important for the students interviewed to have an opportunity not only to check the accuracy of the transcriptions, but also to assess whether the data had been interpreted the way they were intended (Torrance, 2012). As the interview transcriptions were analyzed, I could ask the interviewees further questions to guarantee the findings were true reflections of the information they shared during the interview process. Making sure the participants were comfortable helped with this process. The participants were also offered the option of having a follow-up meeting so they could correct or change any of the information they felt was not correct (Torrance, 2012).

Thick, Rick Description

Within this action research, I used thick, rich description. Thick, rich description refers to using as much detail and as many examples as possible when analyzing the data (Creswell, 2014). I provided as rich a description of the methods as possible, giving the audience a chance to "see" the participants and the setting they were in throughout each research method. Providing explicit details about the research participants, processes used throughout the study, and analyses gave a clear depiction of the research (Tracy, 2013). Attention was paid to the description used, making sure to use factual information and taking special efforts not to distort or misinterpret any of the findings (Mertler, 2017).

This helped the research by giving different perspectives about any themes that were found, making the results more realistic and adding to the value of what was found (Creswell, 2014).

Plan for Sharing and Communicating Findings

I first shared the results of this action research with the students who participated in the study. I also shared the final results of the data analysis informally with all three of the participating geometry classes. The participants were provided with an additional day and time after school for any students who wished to hear about the findings and what was planned on being done with the results in more depth. The students were given a chance to ask any questions about the finality of the action research. This gave them the chance to look at the information being offered in the research and allowed them to guarantee that their privacy had been maintained (Drew et al., 2008).

I also shared the results of this action research with the teachers in the mathematics department. I went through the results with them at one of our regularly scheduled department meetings after school. This gave them all a chance to look through the findings and to discuss the recommendations I made based on the results. Because they all work together and they all teach differing levels of math, it was important for all of the departmental coworkers to understand the research that had been completed.

I also communicated the results from this action research with administrators at the participating school. This was in the form of a meeting and included the head of the high school, the two assistant heads of the high school, the mathematics department chair, and the two learning support counselors. I went through the action research that was completed, the steps taken, and the results. I explained the suggestions and recommendations that emerged based on the results.

Throughout the entire action research, I protected the identities of the participants by not using their names and by refraining from giving identifying pieces of information. This is important because it is the researcher's responsibility to protect the identities of participants (Mertler, 2017). The information given on the student participants was only what was absolutely necessary and if I needed to refer to a single student within the research, they were given a reference number (e.g., Student 1, Student 2, etc.). This gave anonymity to the participants and guaranteed that their personal information was confidential and no one would be able to identify them through the research (Mertler, 2017).

CHAPTER 4

ANALYSIS AND FINDINGS

The purpose of this action research study was to evaluate the implementation of an adaptive web-based learning environment to personalize geometry instruction and practice for high school students at a private school in North Carolina. I collected quantitative and qualitative data to answer the following research questions: (1) How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry? (2) How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept? (3) What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry? This chapter presents the findings and analysis from a content knowledge pre- and post-assessment, self-beliefs scale, motivation questionnaire, and student interviews. This chapter begins with the quantitative findings and data analysis, followed by the qualitative findings and data analysis.

Quantitative Analysis and Findings

I used a content knowledge pre- and post-assessment, self-beliefs scale, and motivation questionnaire to collect quantitative data. This section includes the results from each, including descriptive statistics.

Content Knowledge Pre- and Post-Assessment

The content knowledge pre- and post-assessment was designed by the researcher and based on the current mathematic curriculum and aligned with the North Carolina state standards for geometry. The assessment contained a total of 30 open-ended questions. It was reviewed by two other geometry teachers for content validity. The maximum score was 100 and the minimum score was 0.

Descriptive statistics for the content knowledge pre- and post-assessment are presented in Table 4.1. The pre-assessment scores ranged from 0 to 43 with a mean of 17.64 and a standard deviation of 9.75. The post-assessment scores ranged from 54 to 98 with a mean of 83.32 and a standard deviation of 9.04.

Table 4.1 *Descriptive Statistics for Content Knowledge Pre- and Post-Assessment (n = 44)*

	Pre-Assessment		Post-Assessment	
	M	*SD*	*M*	*SD*
Total scores	17.64	9.75	83.32	9.04

After determining the data met the assumptions, I performed a paired sample *t* test to compare the means for the content knowledge pre- and post-assessment. There was a substantial difference between the pre-assessment (M = 17.64, SD = 9.75) and post-assessment (M = 83.32, SD = 9.04) scores, $t(43) = -40.13$, $p < .001$. Students performed significantly higher on the content knowledge post-assessment than on the pre-assessment.

Self-Beliefs Scale

I adapted the established Self-Beliefs Scale (Stankov et al., 2012) to measure students' geometry self-efficacy, mathematics anxiety, and mathematics self-concept. The original instrument included six subscales; however, only mathematics self-efficacy, mathematics anxiety, and mathematics self-concept were used for this study. I conducted a reliability analysis with post-intervention data ($n = 44$) and the results showed good reliability for all subscales (Cortina, 1993). The Cronbach's alpha was .91 for mathematics self-efficacy (five items), .85 for mathematics anxiety (four items), and .86 mathematics self-concept (four items).

I used JASP to run both descriptive and inferential statistics. The descriptive statistics for mathematics self-efficacy, anxiety, and self-concept are presented in Table 4.2. Students' self-efficacy scores increased from the pre-intervention questionnaire (M = 4.01, SD = 1.00) to the post-intervention questionnaire (M = 4.22, SD = 0.77). Similarly, students' anxiety scores improved from the pre-intervention questionnaire (M = 3.43, SD = 1.32) to the post-intervention questionnaire (M = 3.56, SD = 1.28). Additionally, students' self-concept pre-intervention questionnaire scores (M = 3.14, SD = 1.12) showed a slight improvement on the post-intervention questionnaire (M = 3.23, SD = 1.04).

Table 4.2 *Descriptive Statistics for Self-Efficacy, Anxiety, and Self-Concept (n = 44)*

	Pre-Intervention		Post-Intervention	
	M	*SD*	*M*	*SD*
Mathematics self-efficacy	4.01	1.00	4.22	0.77
Mathematics anxiety	3.43	1.32	3.56	1.28
Mathematics self-concept	3.14	1.12	3.23	1.04

As a check for normality showed the data did not have a normal distribution, I conducted Wilcoxon signed-rank tests. The output indicated the post-intervention questionnaire scores (Mdn = 4.00) for mathematics self-efficacy were higher than the pre-intervention questionnaire scores (Mdn = 4.00). The Wilcoxon signed-rank test indicated this result was statistically significant, $Z = -2.85$, $p < .01$. The output indicated the post-intervention questionnaire scores (*Mdn* = 4.00) for mathematics anxiety were slightly higher than the pre-intervention questionnaire scores (*Mdn* = 4.00). The result was found not to be statistically significant, $Z = -0.97$, $p = .33$. Similarly, the output indicated the post-intervention questionnaire scores (*Mdn* = 3.00) for mathematics self-concept were slightly higher than the pre-intervention questionnaire scores (*Mdn* = 3.00). The result was found not to be statistically significant, $Z = -0.94$, $p = 0.35$.

Motivation Questionnaire

To measure students' motivation to learn geometry, I adapted the Science Motivation Questionnaire by Glynn (2009). Five subscales were used for this study: motivation, relevance to personal goals, self-determination, self-efficacy, and anxiety. I tested the reliability of the subscales with post-intervention data ($n = 44$) and the results showed good reliability for each subscale, except for one (Cortina, 1993). The Cronbach's alpha was .83 for motivation to learn geometry (eight items), .90 for relevance to personal goals (five items), .85 for self-efficacy (five items), and .83 for anxiety (five items). The one subscale that did not show good reliability was self-determination, which had a Cronbach's alpha of .65 (five items).

I used JASP to run both descriptive and inferential statistics. The descriptive statistics for motivation to learn geometry, relevance to personal goals, self-determination, self-efficacy, and anxiety are presented in Table 4.3. Students' motivation to learn geometry increased significantly from the pre-intervention questionnaire ($M = 3.32$, $SD = 1.32$) to the post-intervention questionnaire ($M = 3.60$, $SD = 1.28$). Similarly, students' relevance to personal goals increased considerably from the pre-intervention questionnaire ($M = 2.32$, $SD = 1.17$) to the post-intervention questionnaire ($M = 3.81$, *SD*

= 1.44). The students rated their self-determination higher in the post-intervention questionnaire (*M* = 3.70, *SD* = 1.02) than in the pre-intervention questionnaire (*M* = 3.45, *SD* = 1.16). Likewise, the students rated their self-efficacy higher in the post-intervention questionnaire (*M* = 3.79, *SD* = 0.99) than in the pre-intervention questionnaire (*M* = 3.51, *SD* = 1.19). Additionally, the students' anxiety scores increased from the pre-intervention questionnaire (*M* = 2.85, *SD* = 1.32) to the post-intervention questionnaire (*M* = 3.04, *SD* = 1.33).

Table 4.3 *Descriptive Statistics for Motivation, Relevance to Personal Goals, Self-Determination, Self-Efficacy, and Anxiety (n = 44)*

	Pre-Intervention		Post-Intervention	
	M	*SD*	*M*	*SD*
Motivation	3.32	1.32	3.60	1.28
Relevance to personal goals	2.32	1.17	2.81	1.44
Self-determination	3.45	1.16	3.70	1.02
Self-efficacy	3.51	1.19	3.79	0.99
Anxiety	2.85	1.32	3.04	1.33

As a check for normality showed the data did not have a normal distribution, I conducted Wilcoxon signed-rank tests. The output indicated the post-intervention ratings (*Mdn* = 3.00) for motivation to learn geometry were higher than the pre-intervention ratings (*Mdn* = 4.00). The Wilcoxon signed-rank test indicated this result was statistically significant, $Z = -3.63$, $p < .001$. Similarly, the output indicated students' ratings for relevance to personal goals were higher on the post-intervention (*Mdn* = 2.00) than the pre-intervention (*Mdn* = 3.00). The Wilcoxon signed-rank test indicated this result was also statistically significant, $Z = -4.52$, $p < .001$. Additionally, the output for self-determination indicated the post-intervention ratings (*Mdn* = 4.00) were higher than the pre-intervention ratings (*Mdn* = 4.00). The Wilcoxon signed-rank test indicated this result was statistically significant, $Z = -2.46$, $p = .014$. The output for the self-efficacy subscale indicated the post-intervention questionnaire scores (*Mdn* = 4.00) were higher than the pre-intervention questionnaire scores (*Mdn* = 4.00). The Wilcoxon signed-rank test indicated this result was statistically significant, Z = -2.81, p =.01. In addition, the output for anxiety indicated the post-intervention questionnaire scores (*Mdn* = 3.00) were slightly higher than the pre-intervention questionnaire scores (*Mdn* = 3.00). The Wilcoxon signed-rank test indicated this result was not statistically significant, Z = -1.85, p =.06.

Qualitative Analysis, Findings, and Interpretations

I gathered qualitative data through conducting a total of 15 interviews to comprehend students' perceptions and experiences with regard to using an adaptive web-based learning environment for geometry. The interviews were semi-structured, informal, and took place during a convenient time for the students. Three themes emerged throughout the analysis of the data: (a) struggles with different aspects of mathematics, (b) positive outcomes of using IXL, and (c) aspects of adaptive learning environments to promote student learning.

I audio recorded the student interviews on an iPad using Voice Record and transcribed them verbatim into a Microsoft Word document. I then imported the interview documents into the web-based qualitative data analysis tool, Delve, for analysis. Interview transcripts were member checked by participants to ensure the information was accurately represented (Onwuegbuzie, Leech, & Collins, 2010; Creswell, 2014). All of the codes created through this data analysis related to the student interviews; however, there were no codes created prior to the analysis process.

I used inductive analysis to analyze the interview data. This type of analysis consists of organizing, describing, and interpreting the data (Mertler, 2017). The initial organization of data began with a first cycle of open coding, allowing for an open-ended approach and engagement in other methods of coding throughout the process (Saldaña, 2016). I reflected for a few days in between coding every two to three interviews in order to allow myself time to grasp the information. The first cycle of coding resulted in a total of 499 codes, such as “improved understanding” and “challenging proofs.”

I analyzed each individual sentence one at a time to allow for simultaneous coding, which allowed for text to be applied to more than one code (Saldaña, 2016). This kept me from losing any important information that may have applied to more than one category or theme. For example, Student 10 said, “But I did notice that I wanted to learn geometry just enough to do the problems in IXL because it was fun.” This statement was given the simultaneous codes *wanted to learn geometry* and *IXL was fun*. Figure 4.1 shows this simultaneous coding being applied during open coding.

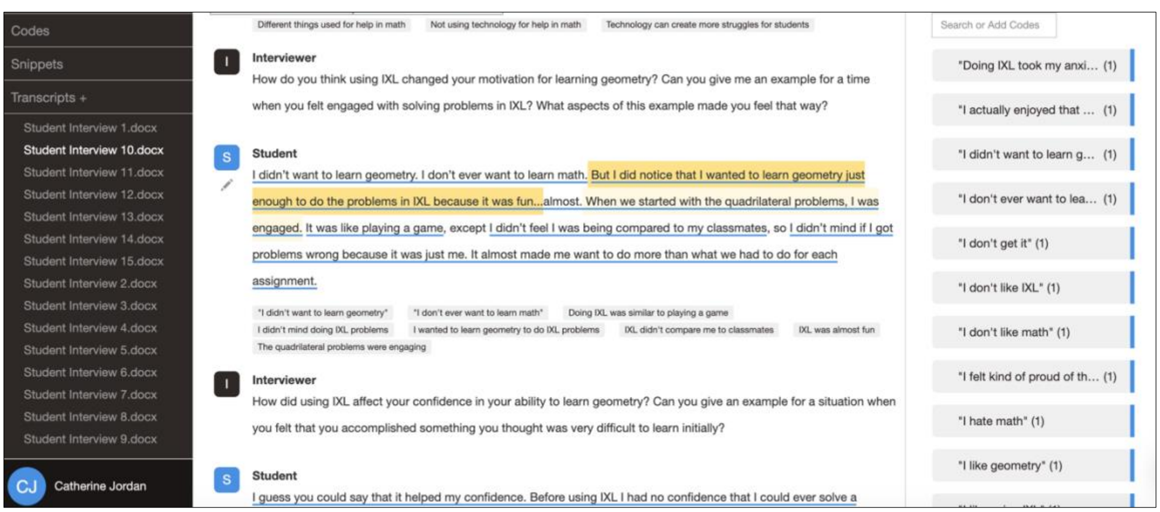

Figure 4.1. Simultaneous coding in Delve.

I also applied in vivo coding because it is useful when working with high school participants and it is helpful with action research (Saldaña, 2016). Using in vivo coding also enabled me to get direct quotes from my participants and relate my categories and themes directly back to my collected data and participants (Creswell, 2014). For example, the in vivo codes of “I hate math” and “I’ve always struggled in math” were applied during this cycle of coding. Figure 4.2 shows an example of in vivo coding being applied in Delve.

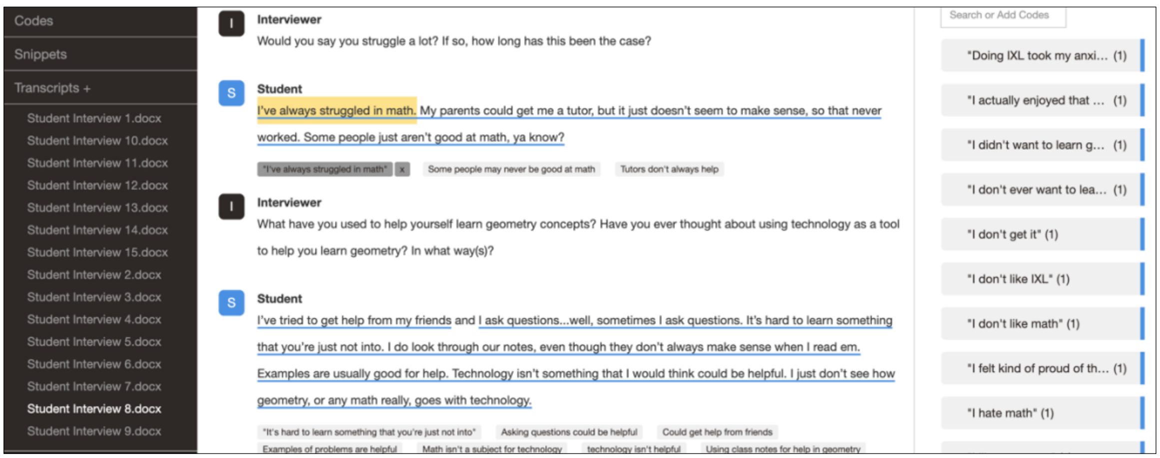

Figure 4.2. In vivo coding in Delve.

I used the research questions to guide the open coding process and to look for ideas that related directly to motivation, engagement, anxiety, and learning. I also looked for ideas and words that were repeated by the participants. I organized the codes found throughout the first open coding cycle in Delve. Once the codes were created, I printed and cut them out. As I cut out the codes, I paid attention to repeated words, ideas, and phrases. I made a list of these on a sheet of paper. This allowed me to begin thinking about how the codes might relate to one another and fit together.

I completed two separate rounds of pattern coding for the second cycle coding in order to organize the vast number of codes created from first cycle coding (Saldaña, 2016). This enabled me to organize the codes into more meaningful categories and to look for codes that might be specific to the research questions of this study (Saldaña, 2016). I started my first round of pattern coding by organizing the codes on a table. I first combined the codes based on the similarities they shared, using the words and phrases I had written down. For instance, I put statements that had a code about motivation into a pile. Likewise, codes that involved geometry were put together and codes that involved technology were put together. I kept my research questions in mind when putting the codes together.

Once I put the codes into piles with similarities, I combined codes that were similar. For example, there was a code created for hating math and there was an in vivo code of "I hate math." I combined these codes into one, as they were both providing the same information from the student participant. Once I combined any necessary codes, I began separating the piles into different ideas. For example, I further separated the pile for technology into different piles based on what separated the codes. I formed a new pile for positive thoughts on technology, a second pile for thoughts about using technology in a math class, a third pile for negative thoughts on technology, and so forth. Likewise, I further separated the original pile for motivation into piles for positive motivation, motivation with IXL, and so on.

As I took each pile and further separated them, I wrote a possible category onto a Post-it Note and set the pile aside. After doing this for every initial pile of codes, I set out every Post-it Note and laid the corresponding codes underneath. In doing this, I was able to take a second look and guarantee each code was in the appropriate place. If I did not feel a code went with the category, I set it aside to look at later. After going through each initial pile and creating categories, I took all of the codes set aside and created categories for them or found the correct category already created to which I felt it belonged. This round of pattern coding resulted in 72 different categories. I began thinking about themes for these categories and tentatively created six themes. Figure 4.3 shows the codes sorted into the initial 72 categories.

Figure 4.3. First round of pattern coding.

I typed up the categories and themes, and peer-debriefed with my dissertation chair to discuss the initial grouping of codes. I looked at how some of the categories and themes went together and how some of them might need to be put into different categories. This allowed me to combine multiple categories into fewer, broader categories. For example, I was able to combine the categories *practice is helpful*, *IXL is* *good practice*, and *IXL-personalization/individualized/independent* into one single category of *personalized practice.*

After another round of peer debriefing with my research chair and two colleagues, I was able to narrow my data into twelve categories and three themes. Ultimately, the three themes derived were (a) struggles with different aspects of math, (b) positive outcomes of using IXL, and (c) aspects of adaptive learning environments to promote student learning. A compiled list of corresponding themes, categories, and codes can be found in Appendix I. Figure 4.4 illustrates the arrangement of categories into themes.

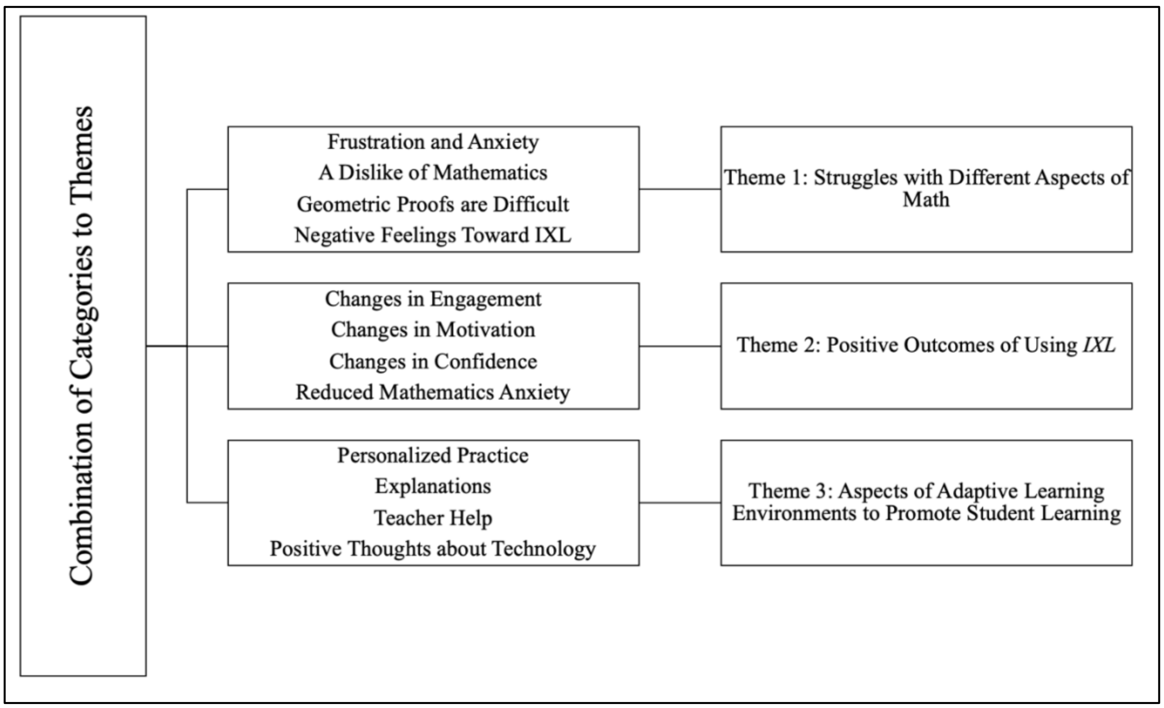

Figure 4.4. Arrangement of Categories into Themes.

Qualitative Themes and Interpretations

Three primary themes emerged through the analysis of the qualitative data from the student interviews: (a) struggles with different aspects of math, (b) positive outcomes of using IXL, and (c) aspects of adaptive learning environments to promote student learning.

Struggles with Different Aspects of Math

In the interviews, students discussed their struggles with mathematics throughout their educational careers. Students related their difficulties with the subject of mathematics in general, as well as specific struggles with geometry and geometric proofs. Furthermore, students cited troubles they experienced when technology was used in their math courses. Additionally, students mentioned the frustration and anxiety these struggles caused throughout their mathematics classes. Overall, students expressed that they struggled with many different aspects of math, causing a dislike of the subject. These struggles included (a) frustration and anxiety, (b) a dislike of mathematics, (c) geometric proofs are difficult, and (d) negative feelings toward IXL.

Frustration and Anxiety

Anxiety about mathematics is just one reason for students' struggles in the subject (Heyder et al., 2019; Ramirez et al., 2018) and it tends to increase as students get older (Olson & Stoehr, 2018). For this study, frustration and anxiety is defined as the negative feelings students get as they attempt to work through mathematics problems, and the negative relationship students feel they have with mathematics. The student interviews conducted in this study shed light on students' thoughts about mathematics causing frustration and anxiety. Though there were both positive and negative feelings from participants, there was a strong sentiment of frustration toward mathematics. Student 13 explained her frustration with math by saying, "You have to remember that stuff years later. I feel like all we do is memorize and then forget it, and then we're trying to relearn it while learning new information. This is my problem with math." Student 4 explained a similar feeling,

> Sometimes you can't even understand what they're trying to tell you when you get a question wrong, and you keep on getting it wrong, that can be difficult. It can really get you frustrated and it can be kinda annoying.

Student 13 further explained the frustration: "I definitely struggle. It's pretty much always been that way. I don't have the best relationship with math, including geometry. I try hard, but that never seems to make much of a difference when it comes to grades." Additionally, Student 3 explained her frustrations when it came to mathematics, saying, "I struggle a lot. It's hard to remember everything. And it's hard to understand the concepts. And then you have to do the problems. And that just makes it worse. I don't think I've ever been good at math." Though most of the participants were open to the different aspects of mathematics, the overwhelming feeling of frustration was apparent for those who struggled with the subject.

In addition to feelings of frustration, student interviews revealed the underlying anxiety that came from struggling in mathematics for many years. As Student 8 explained, "I've always struggled in math. My parents could get me a tutor, but it just doesn't seem to make sense, so that never worked. Some people just aren't good at math, including me." Student 9 had a similar sentiment, stating, "It's hard to want to do it when you're anxious and you don't understand what you're doing." Student 10 explained the anxiety by expressing, "I have always struggled in math. It doesn't matter what we do, I always have trouble with it. It stresses me out." Students also expressed the long-time struggle of mathematics. Student 12 expressed, "I have always struggled in math. I'm not sure I remember not struggling in math. It's been hard for me forever." Similarly, Student 15 stated, "Math has always been hard, since I started school really. I try, but it just never seems to make sense. And so I've always hated it." Students expressed throughout the interviews that they experienced anxiety associated with mathematics struggles over time.

A Dislike of Mathematics

Whether or not a student is interested in mathematics can affect their attitude about the subject (Degenhart et al., 2007; Mailizar & Johar, 2021), thereby affecting their possible success (Rice et al., 2013). For this research study, a dislike of mathematics is defined as the general dislike of any type of mathematics, mathematics course, production of mathematics work, or learning of mathematics. In the interviews conducted in this study, I asked the student participants about their feelings of mathematics. There was a mix of attitudes toward mathematics; however, there was a strong showing of dislike for the subject. When asked about feelings toward mathematics, Student 8 expressed, "Well, it definitely isn't my favorite subject, that's for sure." When prompted for elaboration, Student 8 explained:

> You know, I've struggled in math and it just doesn't seem to get much easier for me. Geometry hasn't been any different. It's hard and I'm lost a lot of the time. It's hard to learn something that you're just not into.

Other participants had similar thoughts. As Student 10 explained, "Not gonna lie, I hate it. All of it. Math is my worst subject ever." In response to specific thoughts about geometry, Student 10 further expressed, "I didn't want to learn geometry. I don't ever want to learn math." Student 12 articulated, "No offense, but I hate math. All math. I don't get it and it's hard and always one of my worst subjects." Student 15 shared similar thoughts: "Can I be honest? I don't like math. I hate it. It has been horrible for me." Furthermore, Student 3 explained,

> Math's always been hard for me. Because of that, it's not my favorite. I was told geometry was going to be hard, so I came into the class thinking that it would be. And it is. I've struggled all year.

The negative feelings toward mathematics from the participants in this study demonstrate that there is a significant amount of dislike toward the subject.

Geometric Proofs are Difficult

Proofs continue to be a part of the mathematics curriculum throughout the United States, and yet students continue to struggle with writing their own proofs (Healy & Hoyles, 2000; Inglis & Alcock, 2012; Miyazaki, Fujita, & Jones, 2017; Senk, 1985; Weber, 2001; Yang & Lin, 2008). For this research study, geometric proofs are difficult is defined by the struggles students have as they try to work through proofs within a geometry course. Throughout the interview process, students were not specifically asked about proofs; however, the common idea of proofs being difficult continued to be brought up by participants. When discussing difficulties in mathematics, Student 12 expressed, "I'm gonna go back to the proofs. I know most of us struggle with those stupid things. Again, no offense. They're just hard." Student 5 voiced a similar thought when discussing struggles in geometry: "The proofs have been very difficult to do." When Student 13 was asked about struggles in geometry, she stated, "I didn't think there'd be any way I could solve a proof, especially on my own." Student 9 explained that his decision to voluntarily take a future math class depended on whether or not proofs would be involved, saying, “I guess it depends on how many proofs we’d have to do. Because that might change my mind. You include proofs? No way!” Overall, students expressed similar feelings about the difficulties experienced with performing geometric proofs.

Negative Feelings Toward IXL

Technology can be a useful tool when trying to help students learn mathematics; however, not all students will see it as something that helps them learn the material (Montrieux et al., 2016; Phillips et al., 2020). When students do not see the benefits of using a technology, they are unlikely to use it or be positively influenced by it (Mailizar & Johar, 2021). For this research study, negative feelings about IXL were defined as any negative feeling a student had before, during, or after the intervention of the adaptive web-based learning environment. As Student 10 explained when asked about his feelings on using IXL:

> I’d never thought about using a technology before because I struggle with that, too. I don’t need to struggle with something that is supposed to be helping me. I thought you were crazy when you said we were going to use it. I just assumed that it was going to be another thing in a math class that I couldn’t do. I was pretty closed-minded about it. I didn’t think it would do anything except make it harder for me. I just knew it wouldn’t help me learn geometry.

Student 8 summed up her feelings about IXL by stating simply, “I don’t like IXL.” When asked to further explain her feelings, she said, “It makes me do work and it isn’t like I enjoy math work. I don’t learn like that.” Student interviews showed students had negative feelings toward IXL, especially at the beginning of the intervention.

During the interview process, a few students expressed frustrations with using IXL. Student 13 explained her frustrations with the technology by saying, “I would get a lot of problems wrong and I’d be really frustrated because I thought I knew how to do it. I wasn’t really reading the explanations they gave because I was so frustrated.” Additionally, Student 2 explained his thoughts:

> IXL kept my anxiety the same, if not made it worse. When I used paper and pencil to solve a problem, I could check the answer on my own and typically I would figure out my mistake. When I did problems on IXL, I was always afraid that my score would drop a whole bunch when I got a problem wrong, so I became more and more afraid to submit my answer, especially when I wasn’t sure if I was right or not. Because you always dropped more points when you got a problem wrong then the points you would add for getting a problem right. It could be frustrating for sure.

The many different aspects of technology can make it frustrating to students as they try to use it for learning.

Furthermore, some students were afraid that using IXL would be distracting. Student 12 explained, “I just didn’t want another distraction when I already struggle in math enough.” Students expressed a slight fear that this tool designed to help them in mathematics might actually make it more difficult to learn because of distracting factors.

The theme of struggles with different aspects of math conveyed the fact that many students have difficulties with mathematics, leading to a dislike of the subject. It was divided into the following four categories: (a) math causes frustration and anxiety, (b) a dislike of mathematics, (c) geometric proofs, and (d) negative feelings toward IXL

Positive Outcomes of Using IXL

Though the student interviews revealed ways in which the students struggled in mathematics, students also expressed that using IXL was beneficial for them in terms of improving their performance, engagement, and motivation to learn geometry. There has been an increase in the use of adaptive web-based learning environments in the field of mathematics to help promote learning within the classroom. These technologies can help students better understand how they learn (Khosravi et al., 2020), keep them engaged (Inan et al., 2020; Mohamad et al., 2018; Amos, Sharma, & John, 2020), and help improve their problem-solving skills (Lin et al., 2020). Additionally, adaptive web-based learning environments can have a positive effect on students' attitudes, motivation, and ability to learn (Mailizar & Johar, 2021; Gu & Lee, 2019; Amos, Sharma, & John, 2020; Gu & Lee, 2019). In this study, students expressed that there were positive outcomes of using the adaptive web-based learning environment, IXL. These positive outcomes included (a) changes in engagement, (b) changes in motivation, (c) changes in confidence, and (d) reduced mathematics anxiety.

Changes in Engagement

Students can be kept engaged with their learning by using adaptive web-based environments (Herbst & Brach, 2006; Inan et al., 2020; Ko & Knuth, 2009; Segal et al., 2018; Amos, Sharma, & John, 2020). For this study, changes in engagement were defined as the positive, and at times surprising, feelings students had regarding engagement within the mathematics classroom throughout the intervention. Student participants discussed the engagement they witnessed during the intervention. Student 2 described the engagement he saw throughout his class, saying, "I did see a lot of students more engaged with doing math problems when they were using IXL." Student 14 explained the engagement of both himself and his classmates, stating, "I like that it kept kids engaged and focused during class." He further described how personal competition within IXL contributed to his own engagement: "I just competed with myself, which was good because it kept me engaged and wanting to do problems." Student 6 elaborated on how IXL kept her engaged:

> I was kinda engaged with all of the assignments we had to do. I wanted to see how many I could get right and get to, like, our goal. The proof problems had me pretty engaged because I felt I could do it better on the iPad than just on a worksheet.

Student 12 added to the sentiment of feeling engaged, saying,

> I tend to struggle to stay on task, but knowing my teacher could see what I was doing made me stay engaged. I can't believe I'm going to say this, but I felt engaged when doing the similar triangle proofs.

Student 7 related her engagement to her success, explaining, "The more successful I was, the more engaged I felt." The overall feeling of engagement was evident throughout the student interviews.

One aspect of IXL that many students brought up with engagement was problems involving quadrilaterals. The following quotations show the ways in which these student participants equated engagement with solving quadrilateral problems on IXL:

> Solving the quadrilateral problems had me engaged because I was able to get in the zone and knock them out. That was one of the times when I went past the goal

> of 80. I kinda just wanted to keep going. There was something about doing it in the app that made it more enjoyable and easier to understand. (Student 9)

> I was always engaged with solving problems in IXL, but I think I was really engaged when we had to determine whether or not a quadrilateral was a parallelogram. I like the different thinking and the fact that it was incorporating proofs into the problems. (Student 14)

> The quadrilateral problems got me engaged because they were the first ones and I wanted to be able to do it so I could compete with my friends. We wanted to be the first one to get to our goal of 80. The problems felt different. I know they were the same as the ones we'd just be doing in our packets, but for some reason they felt like ones that I could do. So I was engaged from the beginning. (Student 15)

Evidence from the student interviews supported the overwhelming feeling of engagement throughout the intervention.

Changes in Motivation

Motivation is an important factor that affects student learning and influences student achievement (Herges et al., 2017; Keys et al., 2012). Supporting students when they learn mathematics can increase their motivation, leading to increased success (Montrieux et al., 2016; Gu & Lee, 2019). For this study, changes in motivation referred to the positive desire to complete assignments, to finish problems correctly, and to learn geometry that resulted from using IXL. There were several factors of motivation to which students referred throughout the interview process. Student 4 discussed the fact that he was more motivated to complete problems using the intervention: "There is definitely more motivation for me to work through the problems in IXL than there are to work through problems in our packets." Student 3 discussed multiple factors of motivation created by using IXL, including the motivating factor of competition:

> I liked the way we only had to get to a score of 80 instead of 100. Going to 100 would seem impossible, but I felt like I could get to 80. So I was motivated to get that score. And it was kind of motivating to see who could get to 80 first. I was also motivated to stay on task because I knew my teacher could see what I was doing. If my attention drifted off, she would know, even if I was virtual that day. So that kept me motivated to keep going until I was done with the assignment.

Student 14 expressed a similar feeling of being motivated by competing, saying,

> I feel I'm always motivated to learn, so I was already motivated to learn geometry. But using IXL allowed me to compete with myself, so I wanted to learn the concepts in order to know what to do for the problems I was given.

Similarly, Student 15 related his motivation from IXL to playing a game and wanting to be included:

> IXL was different. It felt like more of a game, so I wanted to learn geometry so I could play. I didn't wanna be left out, you know what I mean? So that made me motivated to learn the lessons.

Many of the student participants felt motivated by the competitive aspect IXL could provide.

Students also discussed their motivation for learning geometry as well as being successful at learning geometric concepts. Student 9 explained, "For some reason, when I was doing the IXL, the stuff just made sense, so it made me want to do it more. I kinda wanted to keep learning it because I could do it." Student 5 shared a similar feeling of motivation:

> Well, it has made me want to learn how to do the problems so that I get them right. When you work through regular problems in your packet, you don't know if you're getting them right or not, so there isn't any motivation to do it correctly. You're just kinda, like, you're just doing the problems to do them, you know? With the IXL, you want to know how to do the problems so you can do them correctly.

Likewise, when asked about any motivating factors regarding IXL, Student 8 shared, "Once my grades got better, I kinda wanted to do more of it, even though it isn't my favorite. So, yeah, you could say that my motivation for learning geo went up after doing IXL." Overall, students expressed the fact that they were more motivated to learn geometry and solve problems when they understood the concepts and were successful with the use of IXL.

Changes in Confidence

There is a strong correlation between a student's attitude toward geometry and their belief in their ability (Ünlü et al., 2010). The more confidence a student possesses, the better chance they have at being successful in mathematics (Ünlü et al., 2010; Gu & Lee, 2019). For this research study, changes in confidence referred to the positive boost of confidence students felt throughout the intervention. A number of participants felt that solving problems on IXL increased their confidence levels. For example, when asked about her ability to solve problems using the intervention, Student 8 stated, "It just felt good to know I wasn't stupid, ya know? I realized I could actually do some of it."

Similarly, Student 13 expressed her ability to work through problems: “I feel like I was able to build my confidence while working through the problems.” Likewise, when Student 3 was asked about her ability to solve problems using IXL, she replied, “Well, I thought I would struggle more than I did. When I took my time, I actually got a lot of the problems right. Getting those problems right definitely helped boost my confidence.” The student interviews showed there was an enormous increase in student confidence with the use of IXL.

In addition to student confidence in solving problems, students indicated IXL gave them different ways to think about working through problems, which, in turn, boosted their confidence. Student 8 explained,

> And honestly, it gave me different ways to think about problems, which I’m sure will help with problem solving in other math classes. I didn’t think I could do any of the problems actually, so I’m pretty proud of myself.

Other students expressed similar feelings when asked about their experience with confidence as it related to problems on IXL:

> I don’t know if it was the app or what, but the problems on the app just seemed easier, so every time we did an assignment, I feel like my confidence went up. I think the fact that it gives you different problems is good because it forces each student to do their own work and then it gives you problems that you can solve. It doesn’t start out with problems that are impossible, so it lets you build up and gain confidence. (Student 9)

> It got me used to seeing problems differently and made me more confident when I got to hard problems on my tests. (Student 11)

> But I feel a little more confident that I might be able to get through more problems on my own now. I think practicing the problems on IXL gave me the confidence I needed to then try to tackle other problems on my own. (Student 10)
>
> But doing them on IXL made it easier somehow and when I got through that assignment . . . man, I felt good. I didn't even have to ask for help! That was a big confidence boost. (Student 12)

Numerous students reported an increase in their confidence while completing geometry problems throughout the intervention.

Using technology can help students understand and perform proofs (Gardiner et al., 2000; Marrades & Gutierrez, 2000; Segal et al., 2018; Wang & Su, 2015). Student participants described an increase in confidence when it came to working through proofs on IXL. Student 12 summed up his change of confidence after using IXL, stating, "I think my feelings changed after I did the proofs because man . . . if I can do the proofs, then I can do any of the problems." Several other students expressed similar feelings of confidence regarding proofs:

> I was nervous when we got to the problems where we had to prove triangles were similar because I hadn't been able to do any of the proofs. But I end up being able to do them with not a lot of trouble. I mean, being able to do the proofs was a huge boost to my confidence. (Student 9)
>
> I think it helped give me some confidence. The proof problems were a little, ya know . . . they can make you nervous because they're hard. So I think I may not have thought I could do it, but yeah . . . I got through those problems and it made

> me feel pretty good, like I could finally do something that had been really hard all year. (Student 11)
>
> I wasn't sure I'd be able to do the triangle proofs because I thought that would be too hard using technology, but I was pretty happy to see that I could still do the proofs. (Student 14)
>
> Well, I got more problems right than I thought I would. That definitely boosts your confidence. When I was trying to do the assignments with similar triangles, I was sure I wasn't going to get any of them right. It was so hard and I never seem to get any of it right, so I was shocked when I was able to do them. (Student 8)

Being able to encourage a student to maintain a positive attitude about the subject can have a positive impact on their confidence (Kundu & Ghose, 2016; Mailizar & Johar, 2021; Gu & Lee, 2019). Student interviews showed completing the proofs correctly throughout IXL helped to increase students' confidence in their abilities.

Reduced Mathematics Anxiety

Research has shown mathematics anxiety is one reason for students struggling when it comes to learning the subject (Heyder et al., 2019; Ramirez et al., 2018). As students move into secondary school, the anxiety they feel toward mathematics can increase (Olson & Stoehr, 2018). For this study, reduced mathematics anxiety was defined as the decrease in a student's anxiety level when solving geometry problems. Students interviewed in this study expressed the fact that using the adaptive web-based learning environment, IXL, helped reduce their anxiety when it came to mathematics. When asked about the impact of IXL on his anxiety, Student 9 stated:

> I usually feel anxious when I do math. I didn't feel anxious when solving problems in IXL. Honestly, the more we did problems in IXL, the less anxious I felt. I even felt less anxious when it came time to take the tests. I wouldn't say my feelings changed with one specific problem, but more it changed over time. As we did more and more, I felt better about doing problems and my anxiety kinda got less.

Student 8 shared a similar feeling, stating, "I'm used to getting problems wrong, so that didn't bother me. I seemed to get more and more right, so I think you could say that my anxiety got better." Additionally, Student 11 expressed that "having help immediately when you needed it kinda took some of the stress away. Maybe that's why I didn't feel like I had a lot of anxiety when I did IXL." One factor the students mentioned when discussing a decrease in anxiety was the fact that they did not have to get every problem correct when working on IXL. As Student 5 explained, "Not having to get them all right was good because it took some of the anxiety away, not having to be perfect, you know?" Student 15 shared a similar view when discussing his anxiety as it related to working through problems during the intervention:

> Doing IXL took my anxiety away. Believe me, it's always there when I take a test or a quiz or something, but when I did the problems on IXL . . . I don't know. It didn't matter if I got them wrong because I could keep practicing until I got it right. So it took away the anxiety.

Student 5 was even able to use practice from IXL to help calm herself during assessments, saying, "I felt like the problems we did in IXL really helped and I felt calmer than usual when I took the test." It was evident from the student interviews that there was a decrease in student anxiety throughout the intervention.

The theme of positive outcomes of using IXL reflected that there are many benefits for students when using IXL in a mathematics class. Students communicated that using IXL was beneficial for them in terms of improving their performance, engagement, and motivation to learn geometry. This theme was divided into the following four categories: (a) changes in engagement, (b) changes in motivation, (c) changes in confidence, and (d) reduced mathematics anxiety.

Aspects of Adaptive Learning Environments to Promote Student Learning

Using an adaptive learning environment can provide strategies to help support student learning in geometry. When used to supplement instruction, adaptive web-based learning environments can have a positive impact on students (Lin et al., 2020; Ojimba, Gogo, & Chetachi, 2020). In this study, students described different aspects of adaptive learning environments that promoted their learning of geometry. The categories that helped define these features were (a) personalized practice, (b) explanations, (c) teacher help, and (d) positive thoughts about technology.

Personalized Practice

Adapting to the personal learning preferences of students can help them better understand concepts (Alias, 2014). For this study, personalized practice referred to the personalized problems students were given when using IXL throughout the intervention, as well as the gradual increase in the difficulty level of the problems students completed.

Personalized Practice. Adaptive web-based learning environments take the way a student learns information into account by providing personalized practice (Flores et al., 2012). This personalization was something students felt was helpful as they worked through the intervention. Student 9 felt “like it was personalized for me.” Similarly, Student 6 discussed how the personalization gave “us good practice that seems like it’s made just for us.” Student 9 further explained how the personalized practice was beneficial for learning geometry:

> I think it goes at a good pace and it lets each student do their own thing in their own time. That’s helpful because the kids who get it right away aren’t held back by the kids who might not understand it and the kids who are having trouble can get the help they need.

When asked about how the personalization of IXL affected student learning, Student 12 explained that the individual problems allowed for a better learning environment, saying,

> I saw that it was actually helpful and I could go at my pace. No one knew if I was struggling or how long I was taking with my answers. It made me feel better about doing my own thing.

Similarly, Student 8 expressed relief about the adaptive learning environment, saying, “it lets us go at our own pace.” Students also expressed the benefit of having different problems that helped with problem solving:

> It was useful because we got to practice more problems but in a more independent way. We weren’t relying on the teacher or each other and we could figure out problems using different skills and like, tools that were there. (Student 6)
>
> I liked the fact that the problems didn’t all look the same. They all seemed different from each other so I feel that I could solve difficult problems because I know I was able to get through the ones we did on IXL. (Student 3)

The overwhelming positive feelings from students regarding personalized practice with adaptive web-based learning environments show how beneficial these technologies can be when promoting student learning.

Increased difficulty. Many times, students within the same class have different ability levels as well as different interest levels (Arroyo et al., 2014). Research shows using adaptive learning environments can help address this issue by providing students with personal goals (Arroyo et al., 2014; Ojimba, Gogo, & Chetachi, 2020). Furthermore, gradually increasing the difficulty level of problems can increase students' confidence levels (Gu & Lee, 2019). For this research study, increased difficulty is defined by the IXL problems building in level of difficulty as students worked throughout the intervention. Throughout the student interviews, there was a positive feeling about the level of difficulty gradually increasing as students worked through problems. Students overwhelmingly felt this was a good thing when it came to their learning. As Student 14 explained, "It adjusts the level of difficulty depending on the answers you get right or wrong, so I think that's good." Student 9 expressed a similar feeling, saying, "I saw how the problems got more difficult as we went, so that was kinda cool." Additionally, Student 12 stated, "I also like that it started easy and got hard slowly, so it allowed me to feel like I could do it." Student 15 further explained,

> It gives lots of good practice and goes at a pace that's good for you personally. It doesn't give you problems that are too hard until you've practiced enough. It's almost like it can tell when you need harder problems.

Overall, students were in agreement about liking the fact that the problems gradually got more difficult:

> I also like that it doesn't start with hard problems right away. It gives you time to build up to the hard ones. (Student 10)
>
> I like how the problems start out easy in the beginning. You don't start getting harder problems until you demonstrate that you can do the easy ones, so that was good for me. (Student 3)
>
> I think the fact that it gives you different problems is good because it forces each student to do their own work and then it gives you problems that you can solve. It doesn't start out with problems that are impossible, so it lets you build up and gain confidence. (Student 9)

Students were in agreement that using an adaptive web-based learning environment helped them understand and learn information by personalizing the practice and gradually increasing the difficulty level.

Explanations

Adaptive web-based learning environments can be beneficial for students because they provide immediate feedback. Research has shown this helps students in mathematics courses (Phillips et al., 2020). For this study, explanations are referred to as the written help, feedback, and worked-out solutions that were provided to students when they gave an incorrect answer in IXL. Many students expressed that they felt the explanations given in IXL were helpful as they worked through problems during the intervention. Student 9 explained, "Being able to see the steps for how to solve the problems was helpful because you could use it and not have to wait and ask the teacher for help." Student 8 shared a similar sentiment, saying, "I mean, the big benefit has to be the explanations. Getting to immediately see how you should have solved the problem is helpful." Additionally, Student 15 expressed, “Having the explanation when you got something wrong was really helpful,” while Student 14 mentioned, “I think having the explanations when you get an answer wrong is a huge benefit.” Furthermore, Student 13 shared that “knowing we would get an explanation for a wrong answer was helpful,” while Student 5 stated, “The nice thing is that you can look through how to do it right if you get it wrong. That probably helped me the most.” Overall, there was a shared feeling of helpfulness when discussing the explanations given on IXL.

The students also expressed how getting answers explained when using IXL was beneficial for their learning and understanding. When Student 7 was discussing the IXL feedback, she said,

> I think having the right steps when you get something wrong is the biggest benefit because it’s personal to you and your own learning, and you don’t have to wait and ask your teacher. Being able to use IXL to help learn how to do something is good.

Similarly, Student 13 had this to say about how the explanations helped her learning:

> I wasn’t really reading the explanations they gave because I was so frustrated. But when I was working on the similar triangle proportions, I heard one of the kids in my class mention something about getting the problem wrong in order to read how to do it. So I started looking at the explanation and realized that I had the right idea and was just doing my algebra wrong. That’s probably when I realized that using IXL could be helpful if I used it the right way. I read through some of the explanations after getting some of the problems wrong, and I felt like I started to understand it a bit. It made me understand the problems more.

Student 12 discussed how he was one of those students who got problems wrong in order to see the explanation, saying, “If I got something wrong, I’d read through the explanation they gave. Sometimes I’d get a problem wrong immediately just so I could see the explanation of what I was supposed to do. That actually helped a lot.” When asked why this was helpful, Student 12 further explained, “Having help when you get something wrong is a benefit. Geometry can be hard and some of the concepts are confusing, so having an explanation is always a good thing. And we got that.” Student 2 shared a similar feeling, saying, “I knew if I got the problem wrong, I could look through the explanation to make sure I didn’t make any of those mistakes that I saw.” Student 7 used the explanations to solve other problems. She explained, “I was able to problem solve by looking at how they went about solving it and then I could apply it to another problem.” Similarly, Student 11 discussed how using the explanations helped him learn some of the concepts:

> I think having explanations when you get an answer wrong is really helpful. I learn by looking at examples and seeing how things are worked out, so having that in IXL helped me learn, especially when some of the stuff was hard.

The students shared an overwhelming feeling of helpfulness when discussing the explanations given on IXL.

Teacher Help

It is important for teachers to understand that students’ feelings about learning mathematics are continuously changing. Research shows adaptive web-based learning environments can be a beneficial aid for teachers when used to supplement instruction (Walkington & Sherman, 2012; Ojimba, Gogo, & Chetachi, 2020; Lin et al., 2020). In this study, teacher help was defined as the additional support the teacher was able to provide even with the help offered by IXL, as well as the ability the teacher had to set a goal for students, and the ability the teacher had to see the students work in real-time as they completed problems on IXL. Overall, throughout the interview process, it was apparent that students still felt comfortable getting help from the teacher as they worked through the intervention. For example, Student 14 explained, “If I got one wrong and couldn’t understand it from the explanation, I would just ask my teacher for help.” Student 15 elaborated, saying, “Sometimes I would have my teacher help explain the explanation to me.” When asked about getting help during the intervention, Student 4 articulated that she always knew her teacher was available to help her as she worked through problems:

> When you don’t really understand the concept and sometimes you can’t even understand what they’re trying to tell you when you get a question wrong, and you keep on getting it wrong, that can be difficult. It can really get you frustrated and it can be kinda annoying. Whenever that happened, I would just go to the teacher and get help. I could always get help from my teacher.

In addition, Student 10 described how the teacher seeing the specific problems each student was working on meant students could get help any time, regardless of whether they were in the class or not, saying, “I like that the teacher can help you, so if you practice at home, they can still see the problems you might be getting wrong.” Student 11 had a related feeling, saying:

> Knowing your teacher can see you working without having to be right next to you is nice because you can ask a question from anywhere and they can see if you're struggling without having to announce it to the entire class.

Student 10 also appreciated this, stating, "If I kept getting it wrong, usually my teacher would approach me to help before I had to ask her for help." It was clear that students valued being able to receive help from their teacher.

In addition to students appreciating getting help from their teacher, they also felt they benefited from the teacher being able to set goals for them. The standard score for students to reach during the intervention was 80, something that had a huge impact on students. Student 4 explained:

> I like going to 80 on the IXL and not to 100 because 100 would be a lot since it goes up by like 1 point when you get up that high. It would probably take like, double or triple as long to get it done. I feel like it would take the fun away in using IXL.

Student 3 agreed, saying, "I also like how the teacher can choose how much you do. I don't think I would have benefitted as much if we had to get to 100 on every assignment." Student 7 elaborated, stating, "If we had to do all of the problems and be perfect, man, I don't know that any of us would have done well. It would have lost its purpose and I don't think we would've learned anything." Having the teacher set a specific goal was something that was helpful for students throughout the intervention.

Overwhelmingly, the students expressed the fact that knowing the teacher could see their work as they completed assignments kept them motivated and on task. As Student 12 explained, "I tend to struggle to stay on task, but knowing that my teacher could see what I was doing made me stay engaged and focused. It's helpful because it keeps you on task." Student 5 gave a parallel statement, saying, "Knowing that the teacher could see what I was doing was good because it kept me from getting distracted." Additionally, when Student 3 was asked about how IXL was beneficial, she indicated, "I was motivated to stay on task because I knew my teacher could see what I was doing. If my attention drifted off, she would know, even if I was virtual that day." Other students explained that not only did they like that having the teacher see their work kept them on task, they liked the fact that their teacher could see their work and know when they were getting the problems incorrect. Student 13 expressed this by saying, "I think the fact that the teacher can watch what you're doing is good because it keeps kids on task and they can send me notes when they know I'm struggling." Similarly, Student 10 stated, "Knowing that the teacher can see what you're doing is good because it keeps you on task and she can see if you're constantly getting the problems wrong." Overall, students expressed the ability of their teacher to see their work as a benefit of working through problems on IXL.

Positive Thoughts About Technology

Research shows using adaptive web-based learning environments can help students better develop their mathematical problem-solving skills (Phillips et al., 2020; Lin et al., 2020). In addition, students who have positive thoughts about using technology are more likely to benefit from it (Mailizar & Johar, 2021). For this research, positive thoughts about technology referred to the general positive feelings students had about using technology in a mathematics course as well as the changing mindsets students had about technology as they went through the intervention.

Most students had a positive change of opinion when it came to using an adaptive web-based learning environment in their mathematics class. As Student 1 stated, “I thought using a website was going to be more challenging than it was, but it helped me in the end.” Student 6 shared similar feelings:

> I just thought it was going to be hard. Any time we do something new, especially in math, it’s usually hard. But this was kinda . . . different in a good way. If you kept an open mind, it was actually kinda helpful because you got to go at your own pace and you got help when you needed it. I mean, I liked it more than I thought I would. I thought it was going to be really hard and take a really long time, but it didn’t.

When asked about his feelings toward using IXL, Student 15 expressed, “From the beginning, when I realized we could make it a game, well, that kinda changed my thoughts. For once, I could see myself having fun in a math class.” Student 8 summed up the majority feeling after using IXL:

> Ok, so I may have been wrong about math and websites. I still hate IXL because I feel like we were tricked into doing math problems, but . . . like . . . my grades got better and I got some stuff right, so I have to give props. It was probably helpful and we just didn’t know it.

The overall shift in students’ attitudes by the end of the intervention was overwhelmingly positive.

It was evident that there were differing thoughts about technology from the students; however, most students ended the intervention feeling positive about the way technology could help them learn geometry. For example, while Student 10 declared “I try to avoid technology if I can," Student 1 asserted, "Using technology is almost like having someone there to help you when you don't know what you're doing." The majority of students were open to trying a technology. When students were asked whether or not they would be willing to use technology in their mathematics class, many agreed that they were:

> I think at this point, where we are as students, and you know, just in general, we have to be open to technology for all the stuff we do. I'm used to using technology for most things, so I didn't mind trying it. I mean, if it's going to help, then why not, right? (Student 9)
>
> I think I'm open to anything that would be helpful. I'm down for anything that helps. (Student 13)
>
> I think if you can find the right website for your students, it can be helpful. Obviously, I found that using IXL was helpful. (Student 10)
>
> I think it's kinda cool to use a website for a math class because it's something different and you can kinda go at your own pace. You can get more time if you need it, but you aren't stuck waiting for other kids to get it. Learning the same way all the time is difficult, but when you change it up, it gives you another perspective. (Student 6)
>
> Technology can really help because it's like, I kinda understand technology since like, we're living in technology, you know? (Student 4)
>
> I think I was open to it. I kinda feel that we should be able to use anything that helps us, as long as we're getting the concepts down. And we've been using

> technology in school for what feels like forever, so, I don't think using technology was a problem. (Student 11)

The overwhelming feeling from students was that they were open to using technology within the classroom, especially with the amount of technology to which they were exposed. As Student 8 explained, "I think all students are used to technology now, especially with this pandemic and all, so I didn't really see anything hard about it. I was happy to try it." By the end of the intervention, it was evident that students had positive feelings about using an adaptive web-based learning environment to help them learn geometry.

The theme of aspects of adaptive web-based learning environments reflected the fact that there are numerous aspects of these technologies that promote student learning. Throughout the interviews, students indicated using an adaptive web-based learning environment could provide strategies to help support learning in geometry. The categories that helped define these features were (a) personalized practice, (b) explanations, (c) teacher help, and (d) positive thoughts about technology.

Chapter Summary

The focus of this chapter was to present the findings and analysis from a content knowledge pre- and post-assessment, Self-Beliefs Scale, Motivation Questionnaire, and student interviews. I collected both quantitative and qualitative data to answer the following research questions: (1) How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect high school students' knowledge of geometry? (2) How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept? (3) What are high school students' perceptions about using an adaptive web-based learning environment when learning geometry? This chapter began with the quantitative findings and data analysis, followed by the qualitative findings and data analysis.

CHAPTER 5

DISCUSSION, RECOMMENDATIONS, IMPLICATIONS, & LIMITATIONS

The purpose of this action research study was to evaluate the implementation of an adaptive web-based learning environment to personalize geometry instruction and practice for high school students at a private school in North Carolina. This chapter presents the findings in relation to the research questions as well as the literature on mathematics teaching and learning in K–12 and adaptive web-based learning environments. Furthermore, implications and limitations are discussed.

Discussion

To answer the research questions guiding this study, I merged the quantitative and qualitative data and examined them in relation to the literature surrounding mathematics teaching and learning and adaptive web-based learning environments. The discussion is divided into three separate sections, one for each research question.

Research Question 1: How and to What Extent Does Implementing Personalized Geometry Instruction and Practice Through an Adaptive Web-Based Learning Environment Affect High School Students' Knowledge of Geometry?

Results of the current study showed the students overall improved their knowledge of geometry after using IXL. There was a significant difference between the pre-assessment (*M* = 17.64, *SD* = 9.75) and post-assessment (*M* = 83.32, *SD* = 9.04) scores of student participants. Students performed substantially higher on the content knowledge post-assessment than on the pre-assessment. This demonstrates that high school students' knowledge of geometry was positively affected by the implementation of an adaptive web-based learning environment. As the results from this research show, using adaptive web-based learning environments in a mathematics classroom can be a great way for educators to supplement and support the learning experiences of their students.

These results align with previous research asserting that students who have support when learning mathematics are likely to increase their test scores (Montrieux et al., 2016), as well as further develop their problem-solving skills (Lin et al., 2020). These results also support prior research that show using adaptive web-based learning systems can help students increase their problem-solving skills and their learning performance (Lin et al., 2020; Amos, Sharma, & John, 2020; Ojimba, Gogo, & Chetachi, 2020). Using this adaptive web-based learning environment helped gain students' interest, which overall can help overall students become more successful (Rice et al., 2013; Amos, Sharma, & John, 2020; Meke et al., 2019). IXL was able to help students take control of their learning experience, which supports prior research about adaptive web-based learning environments helping students better understand the way they learn (Khosravi et al., 2020).

It has been determined that students enjoy using technologies for explorations and investigations (Koyuncu et al., 2015; Segal et al., 2018). Additionally, these technologies can help students visualize problems as well as compare answers with their classmates

(Vesin et al., 2018). Overall, the results of this study support previous research that showed adaptive learning environments can have a positive effect on students in a mathematics classroom and can be used to foster student learning.

Research Question 2: How Does Using Personalized Geometry Instruction and Practice Through an Adaptive Web-Based Learning Environment Affect Students' Motivation to Learn Geometry as Well as Their Mathematics Self-Efficacy, Anxiety, and Self-Concept?

The primary motivation for this research question was to determine how using personalized geometry instruction and practice through an adaptive web-based learning environment affected students' motivation to learn geometry, mathematics self-efficacy, anxiety, and self-concept. Overall, students felt IXL was a beneficial tool in terms of motivation to learn geometry, mathematics self-efficacy, anxiety, and self-concept. The results regarding this research question are divided into four categories: (a) motivation to learn geometry, (b) mathematics self-efficacy, (c) mathematics anxiety, and (d) mathematics self-concept.

Motivation to Learn Geometry

Previous research has shown it is difficult to motivate students to want to learn mathematics when they do not understand it and continuously perform poorly (Bhagat & Chang, 2015). Furthermore, it has been determined that mathematics anxiety is one reason students tend to struggle in the subject (Heyder et al., 2019; Ramirez et al., 2018), typically worsening as students move throughout their educational career (Olson & Stoehr, 2018). This research was supported by both quantitative and qualitative results from this study.

Quantitative results from this study showed students' motivation to learn geometry increased considerably from the pre-intervention (*M* = 3.32, *SD* = 1.32) to the post-intervention (*M* = 3.60, *SD* = 1.28). Additionally, students' relevance to personal goals increased from the pre-intervention (*M* = 2.32, *SD* = 1.17) to the post-intervention (*M* = 2.81, *SD* = 1.44). These results were supported by the student interviews. As Student 8 explained when discussing the motivating factors of IXL, "Once my grades got better, I kinda wanted to do more of it, even though it isn't my favorite. So, yeah, you could say that my motivation for learning geo went up after doing IXL." Student 14 expressed a similar feeling of being motivated by the competitive aspect of IXL, stating,

> I feel I'm always motivated to learn, so I was already motivated to learn geometry. But using IXL allowed me to compete with myself, so I wanted to learn the concepts in order to know what to do for the problems I was given.

Student 9 discussed the motivating factor of learning geometry due to having the ability to understand it, "For some reason, when I was doing IXL, the stuff just made sense so it made me want to do it more. I kinda wanted to keep learning it because I could do it." This affirms previous research asserting that students are more likely to be motivated to learn math if they are enjoying what they are doing (Bhagat & Chang, 2015; Muir, 2019; Amos, Sharma, & John, 2020), and if they believe that the technology they are using is beneficial (Mailizar & Johar, 2021). This also supports recent research stating that students are more interested and engaged when using a web-based learning environment, leading to increased student learning performance (Amos, Sharma, & John, 2020; Meke et al., 2019). Overall, results of the quantitative and qualitative data analysis showed the students were more motivated to learn geometry when using IXL.

Mathematics Self-Efficacy

Quantitative and qualitative results from this research study support prior research showing a student's achievement in geometry affects their confidence (Ünlü & Ertekin, 2017; Yüksel et al., 2013). The results from this study also support recent research asserting that using adaptive web-based learning environments can help increase student self-efficacy (Gu & Lee, 2019). The results from this study show that students' self-efficacy increased from the pre-intervention (M = 4.01, SD = 1.00) to the post-intervention (M = 4.22, SD = 0.77). Additionally, the students rated their self-efficacy higher in the post-intervention motivation questionnaire (M = 3.79; SD= 0.99) than in the pre-intervention motivation questionnaire (M = 3.51, SD = 1.19).

In order to have students feel confident about being successful in geometry, they must believe they are supported in and out of the classroom. Many of the participants felt solving problems on IXL increased their confidence levels, supporting the quantitative data. For example, when asked about her ability to solve problems using IXL, Student 13 explained, "I feel like I was able to build my confidence while working through the problems." Similarly, Student 3 explained her ability to solve problems with IXL, saying, "I thought I would struggle more than I did. When I took my time, I actually got a lot of the problems right. Getting those problems right definitely helped boost my confidence." Likewise, Student 11 explained how the confidence gained from working through problems on IXL carried over to other assignments, saying, "It got me used to seeing problems differently and made me more confident when I got to hard problems on my tests." Student 10 summed up the increased confidence from IXL, explaining, "I feel a little more confident that I might be able to get through more problems on my own now."

Overall, there was a significant, positive increase in students' mathematics self-efficacy, supporting previous research that students perform better when they are confident in their abilities (Ünlü & Ertekin, 2017; Yüksel et al., 2013; Mailizar & Johar, 2021; Gu & Lee, 2019).

Mathematics Anxiety

Previous research has shown mathematics anxiety is one reason students tend to struggle in the subject (Heyder et al., 2019; Ramirez et al., 2018) and it typically worsens as students move throughout school (Olson & Stoehr, 2018). Findings from this research study support the prior research. The student participants interviewed in this research study expressed that using IXL helped reduce their anxiety when it came to mathematics. Student 9 experienced a decrease in his anxiety, saying, "I usually feel anxious when I do math. I didn't feel anxious when solving problems in IXL. Honestly, the more we did problems in IXL, the less anxious I felt." Student 15 shared a similar feeling when discussing his anxiety, stating, "Doing IXL took my anxiety away." Using IXL can be one way to help students alleviate anxiety in geometry.

One factor the students appreciated related to their anxiety was the fact that they did not have to get a perfect score when working through problems on IXL. Student 5 explained, "not having to get them all right was good because it took some of the anxiety away." She further discussed her ability to use IXL practice to help keep herself calm during assessments, stating, "I felt like the problems we did in IXL really helped and I felt calmer than usual when I took the test." Students overall expressed a decrease in anxiety throughout the intervention.

The quantitative findings align with the qualitive results, indicating that students' mathematics anxiety was reduced. The results from the self-beliefs scale indicated a reduction in students' mathematics anxiety from the pre-intervention (*M* = 3.43, *SD* = 1.32) to the post-intervention (*M* = 3.56, *SD* = 1.28). Similarly, the results from the motivation questionnaire showed a decrease in students' mathematics anxiety from the pre-intervention (*M* = 2.85, *SD* = 1.32) to the post-intervention (*M* = 3.04, *SD* = 1.33).

Research has shown anxiety about mathematics has a negative impact on a student's mathematics achievement (Ramirez et al., 2018). Being able to identify and address mathematics anxiety can help students experience better achievement (Ramirez et al., 2013). The results from the student interviews and questionnaires in this study affirm that students achieve more mathematically when they are not as stressed about their work. Research has shown that addressing and identifying mathematics anxiety can help students improve their achievement and not shy away from future math courses (Ramirez et al., 2013). The student interview responses supported this notion. Results of the current study support that using IXL is one way to address student anxiety when it comes to learning and practicing mathematics.

Mathematics Self-Concept

Previous research has shown a student's mathematical ability has a significant effect on their mathematical performance (Pajares & Kranzler, 1995; Amos, Sharma, & John, 2020). Often times, there are differing levels of student ability and interest within the same class (Arroyo et al., 2014). Prior research has shown using adaptive learning environments can help address this issue by providing students with personal goals (Arroyo et al., 2014; Ojimba, Gogo, & Chetachi, 2020). Additionally, using adaptive web-based learning environments can help bridge the gap between students with low ability and high ability levels (Ojimba, Gogo, & Chetachi, 2020). The ability of a student to receive immediate support from an adaptive learning environment can provide a positive learning experience (Mavroudi et al., 2018; Mailizar & Johar, 2021; Gu & Lee, 2019).

The quantitative findings support prior research. The questionnaire results from this research indicated a slight improvement in students' mathematics self-concept from the pre-intervention (M = 3.14, SD = 1.12) to the post-intervention (M = 3.23, SD = 1.04). Similarly, the results from the motivation questionnaire showed a significant improvement in self-concept from the pre-intervention (M = 3.45, SD = 1.16) to the post-intervention (M = 3.70, SD = 1.02).

Student interviews also supported previous research about adaptive web-based learning environments supporting student performance. Students expressed a positive feeling about the gradual increase in difficulty level on IXL. Overwhelmingly, students felt this was a positive factor in terms of their learning. Student 14 explained, "It adjusts the level of difficulty depending on the answers you get right or wrong, so I think that's good." Similarly, Student 9 expressed, "I saw how the problems got more difficult as we went, so that was kinda cool." Additionally, Student 12 mentioned, "I also like that it started easy and got hard slowly, so it allowed me to feel like I could to it." These sentiments support the fact that the increasing levels of difficulty provided by IXL help students learn mathematics. Adaptive learning environments can benefit students because they use data that are specific to the learner to customize the learning experience (Khosravi et al., 2020). Adaptive learning environments can be beneficial to all students, whether the students are low-ability, middle-ability, or high-ability. Both the quantitative and qualitative results from this research study show that using IXL helped improve students' self-concept, regardless of ability level. Quantitative results from both the questionnaire and the questionnaire showed improvement in students' self-concept. Qualitative results from student interviews supported this data, indicating a positive correlation between using IXL and student self-concept in a geometry class.

Research Question 3: What are High School Students' Perceptions About Using an Adaptive Web-Based Learning Environment When Learning Geometry?

Previous research has shown students who have access to adaptive web-based learning environments are better able to comprehend mathematical concepts (Ozyurt et al., 2013). In addition, students who believe these technologies are beneficial for learning mathematics are likely to have a more positive attitude about using them (Mailizar & Johar, 2021). Students having a positive and open outlook on technology can make a difference as to whether the technology is useful to their learning. Results of this research study showed students overall have positive perceptions about using an adaptive web-based learning environment when learning geometry. The results regarding this research question are divided into three categories: (a) initial negative feelings, (b) changed perceptions, and (c) positive aspects of using IXL.

Initial Negative Feelings

Though technology can be a useful tool when trying to help students learn mathematics, not all students will see it as something that helps them learn the material (Montrieux et al., 2016; Phillips et al., 2020). At the beginning of the intervention, many students agreed with this sentiment. Student 10 explained his feelings about using IXL, saying, “I was pretty closed-minded about it. I didn’t think it would do anything except make it harder for me. I just knew it wouldn’t help me learn geometry.” Student 8 shared a similar feeling, stating, “I don’t like IXL. It makes me do work and it isn’t like I enjoy math. I don’t learn like that.” Students were also afraid that using IXL would keep them too distracted to learn. As Student 12 explained, “I just didn’t want another distraction when I already struggle in math enough.” The students expressed that many of their negative thoughts about using an adaptive web-based learning environment were at the beginning of the intervention. These initial negative feelings are likely due to the fact that many students have used technologies in math before, but have never had a positive outcome from it. Similarly, many students already struggled with math and felt that using a new technology would make learning the subject even more difficult than it already was. Furthermore, students expressed concern with being distracted by a technology and preferred not to try something that was potentially harmful for their learning.

Changed Perceptions

By the end of the intervention, many students had changed their perceptions about using IXL. Many of the student participants had a positive mindset when it came to using an adaptive web-based learning environment in their mathematics class. Student 1 explained, “I thought using a website was going to be more challenging than it was, but it helped me in the end.” Similarly, when asked about his feelings about using IXL, Student 15 stated, “From the beginning, when I realized we could make it a game, well, that kinda changed my thoughts. For once, I could see myself having fun in a math class.” Student 6 expressed, “I liked it more than I thought I would. I thought it was going to be really hard and take a really long time, but it didn't." Student 8 summed up how the majority of the students felt after using IXL, saying, "I may have been wrong about math and websites." When asked to elaborate, she explained, "My grades got better and I got some stuff right, so I have to give props. It was probably helpful and we just didn't know it." There was a positive shift in students' attitudes toward using adaptive web-based learning environments by the end of the intervention. This positive change in students' feelings is most likely due to the fact that they found using IXL helpful as they tried to learn new geometric concepts. Having immediate feedback and explanations for wrong answers gave students a chance to work their way through problems without having to ask for help. In turn, this increased student confidence and self-efficacy. Additionally, students were able to have the teacher see the problem they were working on, regardless of his or her physical location. This allowed the student to receive help from anywhere, including at home. Furthermore, students expressed that being able to start with easier problems helped them build confidence before the difficulty level increased, leading to a higher motivation to keep working.

Though it was clear that students had differing opinions about technology, most students finished the intervention feeling positive about the way technology could help them learn geometry. The majority of the students were open to trying technology. When the students were asked whether or not they would be willing to use technology in their mathematics class, many agreed that they were. Student 13 exclaimed, "I think I'm open to anything that would be helpful." Similarly, Student 9 said, "I'm used to using technology for most things, so I didn't mind trying it. I mean, if it's going to help, then why not, right?" Student 6 summed up many students' feelings, saying, "I think it's kinda cool to use a website for a math class because it's something different and you can kinda go at your own pace." The change in the students' perceptions further demonstrates the benefit of using an adaptive web-based learning environment to supplement mathematics practice and instruction.

Positive Aspects of Using IXL

Overall, students felt there were many positive aspects of using IXL within their geometry class. When students use an adaptive web-based learning environment, they can have a more personalized learning experience (Mavroudi et al., 2018; Nye et al., 2018). Furthermore, the most used and applied qualities within adaptive learning environments are the personal traits (Normadhi et al., 2019). Additionally, students feel using these technologies can help them learn because of the explanations they receive (Vesin et al., 2018) and the motivation this feedback can provide (Faber et al., 2017; Gu & Lee, 2019).

Results of this research study support previous research. The ability of students to have personalized explanations from adaptive web-based learning environments makes these tools useful for their learning and understanding of geometry. The appeal of these technologies is the fact that they provide individualized support to students and help keep them engaged (Khosravi et al., 2020; Normadhi et al., 2019; Amos, Sharma, & John, 2020). Students agreed with this previous research. Student 1 stated, "Using technology is almost like having someone there to help you when you don't know what you're doing." Similarly, Student 10 mentioned, "I think if you can find the right website for your students, it can be helpful. Obviously, I found that using IXL was helpful." Students had an overall positive feeling about using IXL in geometry.

Personalization was a continuous theme that came up throughout the qualitative data analysis with regard to using IXL. Student 6 explained that IXL gave "us good practice that seems like it's made just for us." Student 12 expressed that the individualization had a positive impact on his learning, saying, "I saw that it was actually helpful and I could go at my pace." Student 9 further explained the usefulness of the personalized practice, stating, it was "helpful because the kids who get it right away aren't held back by the kids who might not understand it and the kids who are having trouble can get the help they need." Additionally, Student 8 expressed relief about using IXL, stating, "it let us go at our own pace." There was an overwhelming sense of favorableness from students regarding IXL and how useful this technology could be when supplementing student learning in geometry.

The results from the qualitative data supported previous research showing adaptive web-based learning environments can help students better develop their problem-solving skills (Phillips et al., 2020; Lin et al., 2020). Students overall were overwhelmingly open to using technology within their mathematics classroom, especially with the amount of exposure they have to technology on a regular basis. As Student 8 expressed, "I think all students are used to technology now, especially with this pandemic and all, so I didn't really see anything hard about it. I was happy to try it." Finding a technology that keeps students engaged can be a great way to support learning in a mathematics classroom. It was evident by the end of the intervention that students had positive attitudes about using an adaptive web-based learning environment to help them learn geometry.

Implications

This research has implications for me as a teacher, for other high school mathematics teachers looking to integrate technology into their mathematics classes, and for future researchers. Three types of implications are discussed: (a) personal implications, (b) implications for implementing personalized geometry instruction and practice through an adaptive web-based learning environment, and (c) implications for future research.

Personal Implications

As a result of this action research study, I have learned several personal lessons that I will use in my mathematics classroom. These include (a) understanding my students' mathematical struggles, and (b) changes to my teaching methods.

Understanding My Students' Mathematical Struggles

Mertler (2017) stated a benefit of action research is the fact that teachers are encouraged to be more engaged with the happenings in their classrooms as well as with their students. Involving myself in this research study enabled me to get a deeper understanding of my students' struggles when it comes to learning mathematics. When I began this program, I knew my students struggled with geometry and writing geometric proofs. Though I tried to help students learn by using different methods of presenting information, I failed to recognize how students' struggles could affect their ability to learn mathematics.

Students not enjoying mathematics can make it difficult for them to want to learn the subject (Muir, 2019). It has been determined that a student's interest in mathematics can affect their attitude about the subject, which affects their ability to be successful

(Degenhart et al., 2007; Rice et al., 2013). Students substantiated this fact in this research study.

In addition to regular struggles to learn mathematics, the student interviews conducted in this study highlighted students' thoughts about mathematics causing frustration and anxiety. Though there were both positive and negative feelings about mathematics from participants, there was a strong sentiment of frustration toward mathematics. Research has shown mathematics anxiety is a big cause of students' struggles when it comes to learning the subject (Heyder et al., 2019; Olson & Stoehr, 2018; Ramirez et al., 2018).

The fact that this research study verified how students' mathematics struggles affect their attitude and success will enable me to better address their needs. I can approach my students with a sense of empathy and understanding that I may have been lacking in my teaching before this study. I plan on becoming more aware of each of my students and their particular struggles as we begin the school year. I will make a better effort to get to know and understand their past history with mathematics and how it is possibly affecting their ability to learn in my classroom. I will create questionnaires to use at the beginning of each semester to find out where each student is mentally in terms of math so I am better able to meet their needs. I will refrain from making assumptions about my students' work ethic and ability, and instead will assist them with making plans to be successful in my class. Acknowledging my students' struggles to learn mathematics can help me better address what they need to help them be successful and have less anxiety toward the subject.

Changes to My Teaching Methods

I began this research study in an attempt to find a way to help my students learn geometry, especially with regard to writing geometric proofs. Though many of the students interviewed in this study expressed the difficulty of proofs in geometry, it is important for them to be able to achieve success when completing their own proofs in a mathematics course. Students who are able to understand the basics of a proof are able to develop a deeper level of thinking (Yang & Lin, 2008). Being able to write a mathematical proof is an important critical thinking skill for a student to possess because it helps with the understanding of mathematical concepts (McCrone & Martin, 2004).

Because students will be expected to produce this deeper-level thinking in their future mathematics courses, it is important to find a way to help them tackle the daunting task of proof writing. It is challenging to motivate students to learn mathematics (Bhagat & Chang, 2015; Muir, 2019), so it is important for me to find ways to positively motivate my students within my own classroom. This study has shown me that even students who have struggled in mathematics, both in geometry and in previous courses, can be motivated and find success with IXL. Knowing the results from this study showed positive feedback from students gives me an increased awareness of how I can motivate my students.

I plan to use IXL on a regular basis to supplement my geometry instruction and to supplement student practice as they learn new concepts. I will create in-class assignments that are related to practice on this technology, as well as homework assignments for students to practice at home. Additionally, I will use IXL as a main form of practice as students work through writing geometric proofs. Furthermore, I will work with my colleagues within my department to help them create lessons and assignments that use the positive aspects of IXL.

Implications for Implementing Personalized Geometry Instruction and Practice Through an Adaptive Web-Based Learning Environment

The results from this research study showed using an adaptive web-based learning environment can be useful in a mathematics classroom for both students and teachers. Findings from this study have implications for many involved in making decisions regarding mathematics curriculum. These are discussed as how they relate to (a) educational technology leaders and (b) mathematics teachers.

Educational Technology Leaders

This research study confirmed that technology can be a motivating factor for students when it comes to learning mathematics. Students have been found to enjoy using technology to explore concepts (Koyuncu et al., 2015; Segal et al., 2018), and it can keep them engaged with the process of learning (Herbst & Brach, 2006; Ko & Knuth, 2009; Segal et al., 2018). Being able to find a technology to motivate students can be a great way to individualize support in a mathematics classroom.

Because the results from this study support previous research about the beneficial factors of using technology in the classroom, it is important for educational technology leaders to find technologies to use in mathematics classrooms. Educational technology leaders should be willing to work with teachers to find adaptive web-based learning technologies that can be incorporated into the curriculum. It is imperative that students have the necessary technological support from these leaders. Additionally, students need technology to be readily available to them. Technology leaders need to be aware of what is available for teachers to use and understand and be able to support the implementation of such technologies. Using technology in a mathematics classroom can help encourage students to do well (Inan et al., 2020; Mohamed et al., 2018; Gu & Lee, 2019; Mailizar & Johar, 2021; Amos, Sharma, & John, 2020), making it important for technology leaders to look for and find technologies that complement what schools and school districts have in place.

Mathematics Teachers

It is important for teachers to understand the fact that not all students will benefit from using technology, and take that into account when they implement technology into their classrooms (Wallace & Witus, 2013). Because some technology can harm a student's chance to improve their mathematics achievement (Perry & Steck, 2015), it is important to integrate technology in a useful way to benefit student learning. Mathematics teachers must be aware that technology is not the only way to get information across to students, making it that much more important to implement technology correctly and effectively (Wallace & Witus, 2013). It is important for teachers to find a balance between teacher-led instruction and utilizing technology in the classroom in order to benefit student learning (Ojimba, Gogo, & Chetachi, 2020; Lin et al., 2020). Teachers need to be aware of the amount of time it takes for implementing a new technology into their classroom, and they must be willing to provide that necessary time. They must be flexible with the unexpected that will inevitably arise within the classroom, and they must be patient with the learning curve that comes any time students and teachers try something new.

Mathematics teachers must also be aware that technology can, at times, be more distracting than motivating for students (Perry & Steck, 2015). Some students do not learn well with technology (Phillips et al., 2020), and others can be distracted by the technology (Perry & Steck, 2015). Mathematics teachers must be willing to try different technologies, and be willing to accept the fact that some may not work for their students or their classroom. It will be important for teachers to have the patience to find the right technology and the right way to integrate it into their classroom.

Mathematics teachers will also need to be aware that their own attitudes can have an impact on how students feel about learning math, even leading to student anxiety about the subject (Dowker, Sarkar, & Looi, 2016; Olson & Stoehr, 2018; Aaron & Herbst, 2019). This also affects the technology a teacher may use in the classroom. Research shows that if a teacher is going to utilize an adaptive web-based learning environment, they have to believe that the technology is beneficial for their students; otherwise, the students will not believe it is valuable (Tatar, Zengin, & Kagizmanli, 2015; Knuth, 2002). Teachers need to take the time to become accustomed to and comfortable with the technology they plan to integrate into their classroom. This can decrease their own anxiety about using technology, allowing for them to better instruct their students (Tatar et al., 2015).

Results from this study, along with previous research, show that using an adaptive web-based learning environment in a geometry classroom can be beneficial for students. If mathematics teachers are open to learning and implementing such a technology into their classroom, students will see the advantages and be able to work towards better success in the subject.

Implications for Future Research

Results from this research study have several implications for future research. These include (a) comparing other adaptive web-based learning environments, (b) using a longer intervention, and (c) using a control group.

Comparing Other Adaptive Web-Based Learning Environments

Though results of this research study showed using IXL was beneficial for students when learning geometry, there are other learning environments that can also help students develop their mathematical abilities (Phillips et al., 2020). Other studies can be performed to compare the different effects of each of these technologies on students. Researchers can compare IXL with one or more of the adaptive web-based learning environments created specifically for geometry, such as GeoGebra, Geometer's Sketchpad, Cabri, and ALEKS. Because these technologies have been found to help students better comprehend mathematical concepts (Ozyurt et al., 2013), it would be valuable to know which characteristics are the most effective.

Using a Longer Intervention

The results of this study came from an implementation of only 7 weeks. Previous research involved considerably longer implementations. For example, Hadas et al. (2000) determined dynamic geometry environments can help students become better at explaining geometric concepts by implementing dynamic geometry activities over the course of a 2-year period. Researchers can implement IXL over the course of a full semester or a full year to see how the results compare to those found in this research study.

Utilizing a Control Group

This action research study did not include a control group. The same students were used throughout the study, and all of them participated in the intervention. Much of the prior research involved the use of control groups to determine the effectiveness of adaptive web-based learning environments. For example, Bhagat and Chang (2015) used a control group and discovered GeoGebra was an effective tool to use when teaching geometry. Future researchers can implement the same strategies used within this research study with the addition of a control group to provide additional information about the effectiveness of IXL.

Limitations

Similar to any research study there are limitations that need to be noted. These limitations are organized into (a) study design, and (b) the researcher.

Study Design

The design of this study led to certain limitations. First, due to the nature of this study being action research, the limitation of a power imbalance existed among the participants and myself as the researcher. The fact that students were interviewed by their own teacher during this study means there was an imbalance in the power relationship between the researcher and the participants (Creswell, 2014). Having a researcher interview participants who were not their own students would potentially limit this imbalance of power. Second, although students were chosen using random sampling, because the focus was on my own students, I used purposeful sampling (Etikan et al., 2016). Using purposeful sampling also led to a small sample size for this research study. Purposeful sampling and a small sample size can lead to bias when analyzing data

(Levine, 2014). Using a different sampling method and a larger sample size could possibly provide less biased results. Third, the duration of the implementation I used in this research study was short, lasting only 7 weeks. Implementing the intervention over a longer period of time can give better and more accurate results when analyzing the data (Levine, 2014). Fourth, the content knowledge pre-assessment was given before instruction while the post-assessment was given after the instruction. This would almost guarantee an increase in the content knowledge post-assessment scores. Using a control group could help provide better data with the pre- and post-assessments. Finally, there was no control group in this research study. All student participants were introduced to the intervention and took the same content knowledge pre- and post-assessments, as well as the same questionnaires. Not having a control group gave me no way to compare how students may have felt without using the adaptive web-based learning environment. Employing a control group could provide an estimate of what to expect if students did not receive the intervention (Levine, 2014).

The Researcher

It is feasible to expect that I contributed additional limitations as the researcher in this study. Though I used triangulation and peer debriefing to help validate the conclusions (Creswell, 2014; Mertler, 2017; Olsen, 2004), it is plausible to expect that my own biases and expectations influenced my interpretations of the collected data. Additionally, the fact that I was both the researcher and the classroom teacher could have led to bias. Member checking and confidentiality measures were taken throughout the research; however, my presence in conducting student interviews could have influenced students to answer in a particular way.

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APPENDIX A

RESEARCH SITE APPROVAL

I give my permission for Catherine Jordan to conduct her research with her ninth- and tenth-grade geometry students at [redacted] School during the Spring semester of 2021.

Head of Upper School Signature

November 4, 2020
Date

APPENDIX B

USC IRB APPROVAL

UNIVERSITY OF
SOUTH CAROLINA

OFFICE OF RESEARCH COMPLIANCE

INSTITUTIONAL REVIEW BOARD FOR HUMAN RESEARCH
APPROVAL LETTER for EXEMPT REVIEW

Catherine Jordan
1244 Blossom Street
Columbia, SC 29208

Re: **Pro00105672**

Dear Catherine Jordan:

This is to certify that the research study **PERSONALIZED GEOMETRY INSTRUCTION: A MIXED METHODS ACTION RESEARCH STUDY IMPLEMENTING AN ADAPTIVE WEB-BASED LEARNING ENVIRONMENT TO SUPPORT HIGH SCHOOL STUDENTS' GEOMETRY PROBLEM-SOLVING SKILLS** was reviewed in accordance with 45 CFR 46.104(d)(1), the study received an exemption from Human Research Subject Regulations on **12/21/2020**. No further action or Institutional Review Board (IRB) oversight is required, as long as the study remains the same. However, the Principal Investigator must inform the Office of Research Compliance of any changes in procedures involving human subjects. Changes to the current research study could result in a reclassification of the study and further review by the IRB.

Because this study was determined to be exempt from further IRB oversight, consent document(s), if applicable, are not stamped with an expiration date.

All research related records are to be retained for at least three (3) years after termination of the study.

The Office of Research Compliance is an administrative office that supports the University of South Carolina Institutional Review Board (USC IRB). If you have questions, contact Lisa Johnson at lisaj@mailbox.sc.edu or (803) 777-6670.

Sincerely,

Lisa M. Johnson
ORC Assistant Director and IRB Manager

APPENDIX C

STUDENT INTERVIEW PROTOCOL

Thank you for taking the time to meet with me today and providing assent to conduct this interview. This interview should occupy no more than 30 minutes of your time. Before we begin, I want to inform you that you are not obligated to answer any question nor do you need to provide a reason for declining to answer. In addition, you may opt out of the interview at any time without consequence. During the interview I will be taking notes. The interview will be recorded and transcribed (excluding any personal identifying information) at a later time. Your identity will remain anonymous. Do you have any questions at this time?

Let me remind you that the purpose of this qualitative research is threefold. I am looking at addressing the following research questions: (1) How and to what extent does implementing personalized geometry instruction and practice through an adaptive web-based learning environment affect ninth- and tenth-grade students' knowledge of geometry?, (2) How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept?, and (3) What are ninth- and tenth-graders' perceptions about using an adaptive web-based learning environment when learning geometry?. There will be two parts to this interview. The first part will address research question number two and the second part will address research question number three.

Before we proceed any further, do you have any questions?

OK, we will begin the interview questions now. Are you ready?

For the first part, we are going to focus on the second research question: How does using personalized geometry instruction and practice through an adaptive web-based learning environment affect students' motivation to learn geometry as well as their mathematics self-efficacy, anxiety, and self-concept?

- In general, what are your thoughts about math? About geometry? Would you say you struggle a lot? If so, how long has this been the case?
- What have you used to help yourself learn geometry concepts? Have you ever thought about using technology as a tool to help you learn geometry? In what way(s)?

- How do you think using IXL changed your motivation for learning geometry? Can you give me an example for a time when you felt engaged with solving problems in IXL? What aspects of this example made you feel that way?
- How did using IXL affect your confidence in your ability to learn geometry? Can you give an example for a situation when you felt that you accomplished something you thought was very difficult to learn initially?
- How did IXL change your anxiety about solving geometry problems? Can you give an example of a time when you felt your feelings change about solving problems in IXL change?
- How do you think your ability to learn difficult concepts is now that you have used IXL? Can you give an example where solving a problem in geometry in IXL became easier than what you thought it would be?

Thank you for your truthful responses. Now we are going to switch to the second part of the interview. For this part we will focus on the third research question: What are ninth- and tenth-graders' perceptions about using an adaptive web-based learning environment when learning geometry?

- Are you used to using technology for your math classes? Can you give examples of how you have used technology in your math classes?
- What are your thoughts about using a website for a math class, specifically geometry? Did your thoughts about using a website for a math class change after using IXL? Why do you think this is? What do you think some of the benefits could be? Is there anything that might be difficult about it?
- Were you open to using technology to help you solve problems in geometry? Why or why not? How did you think you might be able to benefit from IXL in regards to learning geometry?
- Describe the process you went through when working through the assignments you were given on IXL. How did your attitude about using IXL change from the beginning of the implementation to the end? Can you give an example of a problem you worked on where you felt your attitude shift?
- Explain how you think using IXL did or did not help you improve your problem-solving ability in geometry. Can you give an example where you solved a problem you didn't think you would be able to initially?
- Would this be something you think would be useful in the future? Why or why not?
- Comparing your thoughts before using IXL and after, would you sign up for another geometry class for next year?

Is there anything else you feel might be important that we didn't cover? Do you have any final thoughts you would like to add?

That concludes this interview. Thank you very much for your time and for your honesty. Your input will provide beneficial information as I continue my research. I want to remind you that you will be an anonymous participant throughout this research. If needed, may I contact you at a later time if I need to clarify any information? I appreciate your help with this interview and I look forward to sharing my findings with you after everything has been completed. If you have any questions in the meantime, please do not hesitate to contact me at cat.jordan@providenceday.org.

APPENDIX D

SELF-BELIEFS SCALE

[Response Scale: 1-Never 2-Rarely 3-Sometimes 4-Usually 5-Always]

Items
Self-Beliefs Scales

1. **Mathematics self-efficacy**
   a. I can do almost all the work in Mathematics class if I do not give up.
   b. Even if the work in Mathematics is hard, I can learn it.
   c. I am sure I can do difficult work in my Mathematics class.
   d. If I have enough time, I can do a good job in all my Mathematics work.
   e. I am sure I can learn the skills taught in my Mathematics class well.

2. **Mathematics anxiety**
   a. I get nervous answering Mathematics questions.
   b. I get very worried when I have to do Mathematics homework.
   c. I often worry that it will be difficult for me in Mathematics classes.
   d. I feel helpless when answering Mathematics questions.

3. **Mathematics self-concept**
   a. I have always believed that Mathematics is one of my best subjects.
   b. I learn Mathematics quickly.
   c. In my Mathematics class, I understand even the most difficult work.
   d. I get good grades in Mathematics.

APPENDIX E

MOTIVATION QUESTIONNAIRE

[Response Scale: 1-Never 2-Rarely 3-Sometimes 4-Usually 5-Always]

Items

1. I enjoy learning geometry.
2. The geometry I learn relates to my personal goals.
3. I like to do better than the other students on geometry tests.
4. I am nervous about how I will do on geometry tests.
5. If I am having trouble learning geometry, I try to figure out why.
6. I become anxious when it is time to take a geometry test.
7. Earning a good geometry grade is important to me.
8. I put enough effort into learning geometry.
9. I use strategies that ensure I learn geometry well.
10. I think about how geometry will be helpful to me.
11. I expect to do as well as or better than other students in the geometry course.
12. I worry about failing geometry tests.
13. I am concerned that the other students are better in geometry.
14. I think about how my geometry grade will affect my overall grade point average.
15. The geometry I learn is more important to me than the grade I receive.
16. I hate taking geometry tests.
17. I think about how I will use the geometry I learn.
18. It is my fault, if I do not understand geometry.
19. I am confident I will do well on geometry projects.
20. I find learning geometry interesting.
21. The geometry I learn is relevant to my life.
22. I believe I can master the knowledge and skills in the geometry course.
23. The geometry I learn has practical value for me.
24. I prepare well for geometry tests.
25. I like geometry that challenges me.
26. I am confident I will do well on geometry tests.
27. I believe I can earn a grade of “A” in this geometry course.

APPENDIX F

STUDENT MOTIVATION QUESTIONNAIRE ADAPTED ITEMS

Table F.1 *Student Motivation Questionnaire Adapted Items*

Original Questionnaire Item	Adapted Questionnaire Item
1. I enjoy learning the science.	1. I enjoy learning geometry.
2. The science I learn relates to my personal goals.	2. The geometry I learn relates to my personal goals.
3. I like to do better than the other students on the science tests.	3. I like to better than the other students on geometry tests.
4. I am nervous about how I will do on the science tests.	4. I am nervous about how I will do on geometry tests.
5. If I am having trouble learning the science, I try to figure out why.	5. If I am having trouble learning geometry, I try to figure out why.
6. I become anxious when it is time to take a science test.	6. I become anxious when it is time to take a geometry test.
7. Earning a good science grade is important to me.	7. Earning a good geometry grade is important to me.
8. I put enough effort into learning the science.	8. I put enough effort into learning geometry.
9. I use strategies that ensure I learn the science well.	9. I use strategies that ensure I learn geometry well.
10. I think about how learning the science can help me get a good job.	10. Omitted
11. I think about how the science I learn will be helpful to me.	11. I think about how geometry will be helpful to me.
12. I expect to do as well as or better than other students in the science course.	12. I expect to do as well as or better than other students in the geometry course.
13. I worry about failing the science tests.	13. I worry about failing geometry tests.
14. I am concerned that the other students are better in science.	14. I am concerned that the other students are better in geometry.
15. I think about how my science grade will affect my overall grade point average.	15. I think about how my geometry grade will affect my overall grade point average.

16. The science I learn is more important to me than the grade I receive.	16. The geometry I learn is more important to me than the grade I receive.
17. I think about how learning the science can help my career.	17. Omitted
18. I hate taking the science tests.	18. I hate taking geometry tests.
19. I think about how I will use the science I learn.	19. I think about how I will use the geometry I learn.
20. It is my fault, if I do not understand the science.	20. It is my fault, if I do not understand the geometry.
21. I am confident I will do well on the science labs and projects.	21. I am confident I will do well on geometry projects.
22. I find learning the science interesting.	22. I find learning geometry interesting.
23. The science I learn is relevant to my life.	23. The geometry I learn is relevant to my life.
24. I believe I can master the knowledge and skills in the science course.	24. I believe I can master the knowledge and skills in the geometry course.
25. The science I learn has practical value for me.	25. The geometry I learn has practical value for me.
26. I prepare well for the science tests and labs.	26. I prepare well for geometry tests.
27. I like science that challenges me.	27. I like geometry that challenges me.
28. I am confident I will do well on the science tests.	28. I am confident I will do well on geometry tests.
29. I believe I can earn a grade of "A" in the science course.	29. I believe I can earn a grade of "A" in this geometry course.
30. Understanding the science gives me a sense of accomplishment.	30. Understanding geometry gives me a sense of accomplishment.

APPENDIX G

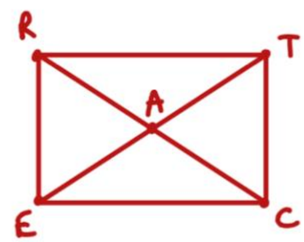
CONTENT KNOWLEDGE PRE- AND POST-ASSESSMENT

PRE-ASSESSMENT/POST-ASSESSMENT

Quadrilaterals (50 total points)

Rectangle RECT is given. Find the indicated variable. (3 pts. each)

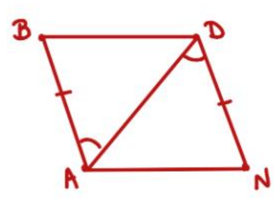
1. Find x if $RC = 5x - 5$ and
   $TE = x + 11$.



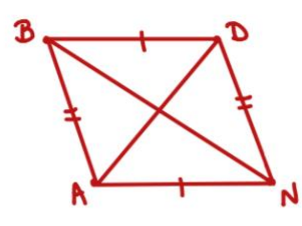
2. Find y if $m\angle ETC = 3y + 9$ and
   $m\angle CET = 2y + 1$.

Determine whether each quadrilateral is a parallelogram. Justify your answer. (3 pts. each)

3.

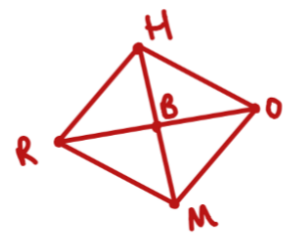


4.



Rhombus RHOM is given. Find the indicated variable. (3 pts. each)

5. Find x if $RH = 6x - 12$ and $RM = 4x + 12$.



6. Find w if $m\angle HRB = 8w - 5$ and $m\angle MRB = 6w + 13$.

Square SQUA is given. Find the indicated variable. (2 pts. each)

7. Find x if $SR = 2x + 55$ and $QR = 14x - 5$.

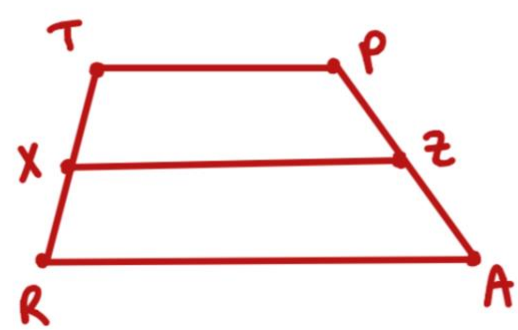
8. Find y if $m\angle SQR = 4y + 5$.

Trapezoid TRAP is given. Find the indicated variable. (3 pts. each)

9. Find x if $TP = 6x - 6$, $XZ = 7x - 4$, and $RA = 38$.

11. Find w if TRAP is isosceles, $TR = 3w + 6$ and $PA = 22 - y$.

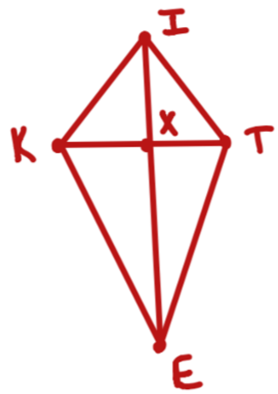
10. Find y if $m\angle T = 8y + 34$ and $m\angle R = 6x - 22$.



Kite KITE is given. Find the indicated variable. (3 pts. each)

12. Find x if $KE = 2x + 2$ and

$TE = x + 11$.



13. Find y if $m\angle IKT = 5x - 15$ and

$m\angle EKT = 2y + 3$.

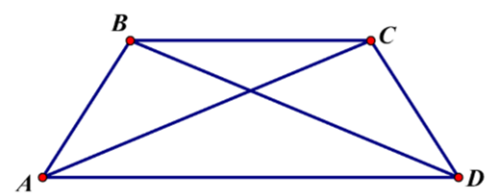
14. Find w if TRAP is isosceles,

$TR = 3w + 6$ and $PA = 22 - y$.

Proofs. Fill in the missing blank for the following proof. (10 pts.)

15. Given: Isos. Trap. ABCD

Prove: $\overline{AC} \cong \overline{BD}$



Statements	Reasons
1. Isosceles trapezoid ABCD	1. Given
2. $\overline{AB} \cong \overline{BC}$	2. ____________________
3. ____________________	3. The diags. of an isos. trap. are ≅ .
4. $\overline{BC} \cong \overline{BC}$	4. ____________________
5. $\Delta ABC \cong \Delta DCB$	5. ____________________
6. $\overline{AC} \cong \overline{BD}$	6. ____________________

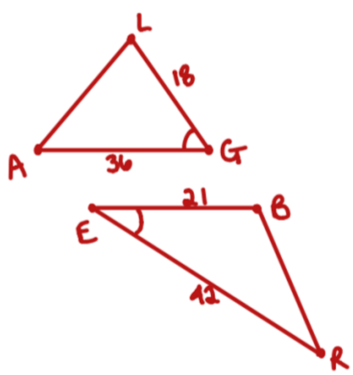
Similar Triangles (50 total points)

Fill in the blank with *always, sometimes,* or *never.* (2 pts. each)

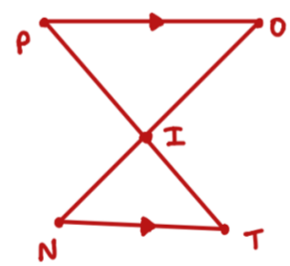
1. A square and a rectangle are ______________________ similar.
2. Congruent polygons are ______________________ similar.
3. A trapezoid and a kite are ______________________ similar.
4. A rectangle and a square are ______________________ similar.
5. Two triangles are ______________________ similar.
6. Two circles are ______________________ similar.

Determine whether each pair of triangles are congruent. If they are, state the reason why and write a similarity statement. If they are not, write *no.* (5 pts. each)

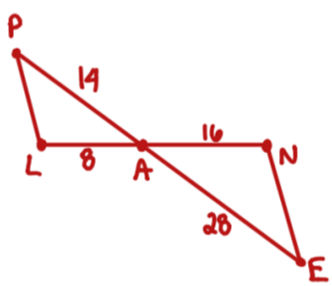
7.



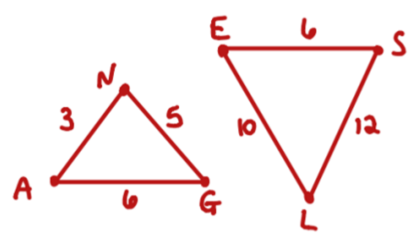
9.



8.

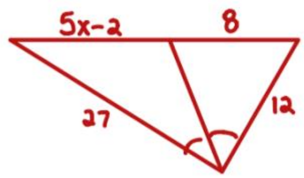


10.

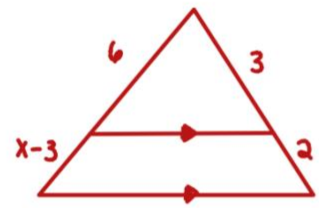


Solve for the value of x in each of the following problems. (4 pts. each)

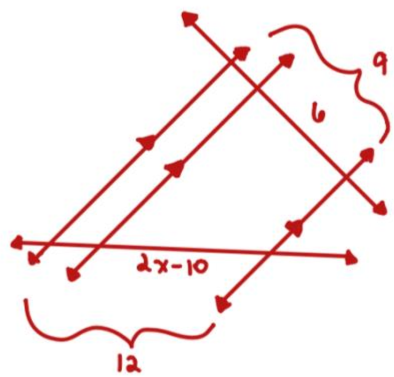
11.



12.

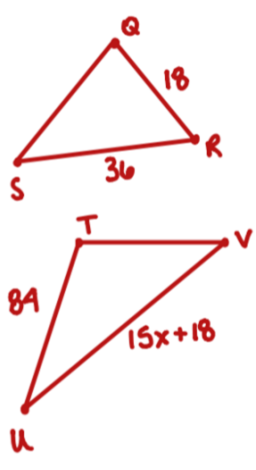


13.

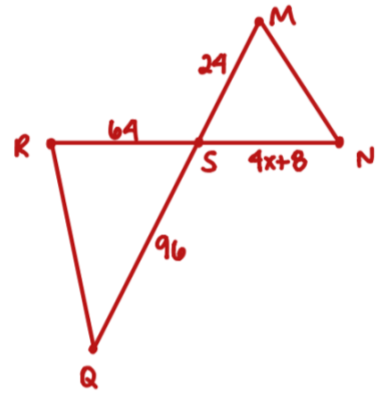


Given the pair of similar triangles, find the value of x. (3 pts. each)

14. $\Delta\, TUV \sim \Delta\, QRS$



15. $\Delta\, SRQ \sim \Delta\, SMN$



APPENDIX H

CONTENT KNOWLEDGE PRE- AND POST-ASSESSMENT RUBRIC

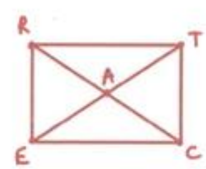
PRE-TEST/POST-TEST

Quadrilaterals (50 total points)

Rectangle RECT is given. Find the indicated variable. (3 pts. each)

1. Find x if $RC = 5x - 5$ and $TE = x + 11$.

   $5x - 5 = x + 11$
   $4x = 16$
   $x = 4$

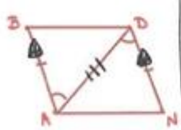


2. Find y if $m\angle ETC = 3y + 9$ and $m\angle CET = 2y + 1$.

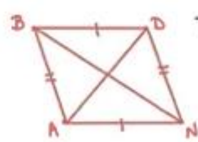
   $3y + 9 + 2y + 1 = 90$
   $5y = 80$
   $y = 16$

Determine whether each quadrilateral is a parallelogram. Justify your answer. (3 pts. each)

3.



yes; 1 pr. opp. sides both // & ≅



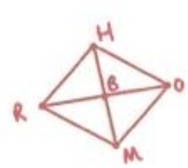
yes; both prs. opp. sides ≅

4.

Rhombus RHOM is given. Find the indicated variable. (3 pts. each)

5. Find x if $RH = 6x - 12$ and $RM = 4x + 12$.

   $6x - 12 = 4x + 12$
   $2x = 24$
   $x = 12$

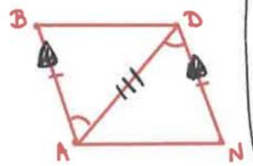


6. Find w if $m\angle HRB = 8w - 5$ and $m\angle MRB = 6w + 13$.

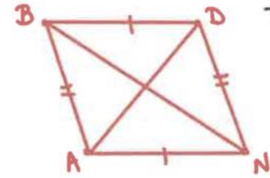
   $8w - 5 = 6w + 13$
   $2w = 18$
   $w = 9$

Determine whether each quadrilateral is a parallelogram. Justify your answer. (3 pts. each)

3.



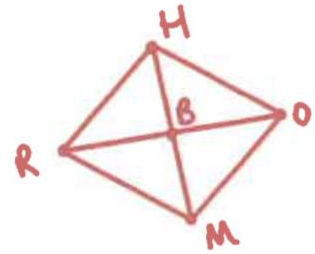
yes; 1 pr. opp. sides both // & ≅



yes; both prs. opp. sides ≅

4.

Rhombus RHOM is given. Find the indicated variable. (3 pts. each)



5. Find x if $RH = 6x - 12$ and $RM = 4x + 12$.

$6x - 12 = 4x + 12$

$2x = 24$

$x = 12$

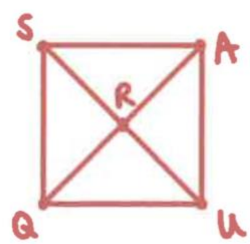
6. Find w if $m\angle HRB = 8w - 5$ and $m\angle MRB = 6w + 13$.

$8w - 5 = 6w + 13$

$2w = 18$

$w = 9$

Square SQUA is given. Find the indicated variable. (2 pts. each)



7. Find x if $SR = 2x + 55$ and $QR = 14x - 5$.

$14x - 5 = 2x + 55$

$12x = 60$

$x = 5$

8. Find y if $m\angle SQR = 4y + 5$.

$4y + 5 = 45$

$4y = 40$

$y = 8$

Trapezoid TRAP is given. Find the indicated variable. (3 pts. each)

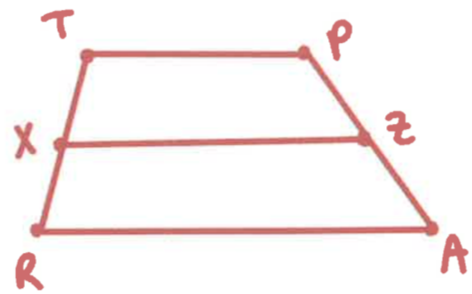
9. Find x if $TP = 6x - 6$, $XZ = 7x - 4$, and $RA = 38$.

$6x - 6 + 38 = 14x - 8$

$6x + 32 = 14x - 8$

$40 = 8x$

$x = 5$



10. Find y if $m\angle T = 8y + 34$ and $m\angle R = 6y - 22$.

$8y + 34 + 6y - 22 = 180$

$14y + 12 = 180$

$14y = 168$

$y = 12$

11. Find w if TRAP is isosceles, $TR = 3w + 6$ and $PA = 22 - w$.

$3w + 6 = 22 - w$

$4w = 16$

$w = 4$

Kite KITE is given. Find the indicated variable. (3 pts. each)

12. Find x if $KE = 2x + 2$ and $TE = x + 11$.

$2x + 2 = x + 11$

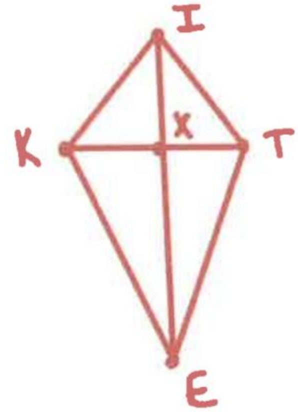
$x = 9$

13. Find y if $m\angle IKT = 5y - 15$ and $m\angle EKT = 2y + 3$.

$5y - 15 = 2y + 3$

$3y = 18$

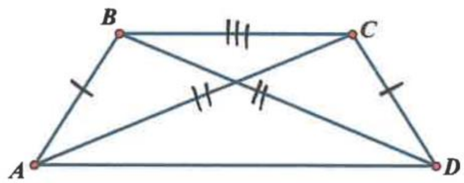
$y = 6$



Proofs. Fill in the missing blank for the following proof. (10 pts.)

15. Given: Isos. Trap. ABCD

Prove: $\overline{AC} \cong \overline{BD}$



Statements	Reasons
1. Isosceles trapezoid ABCD	1. Given
2. $\overline{AB} \cong \overline{BC}$	2. def. isos. trap
3. $\overline{BD} \cong \overline{AC}$	3. The diags. of an isos. trap. are $\cong$.
4. $\overline{BC} \cong \overline{BC}$	4. reflexive POC
5. $\Delta ABC \cong \Delta DCB$	5. SSS
6. $\overline{AC} \cong \overline{BD}$	6. CPCTC

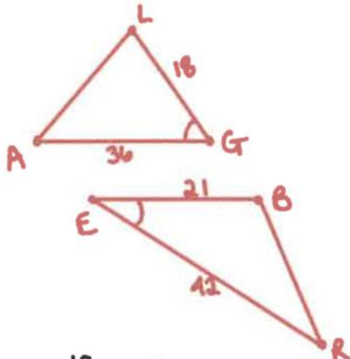
Similar Triangles (50 total points)

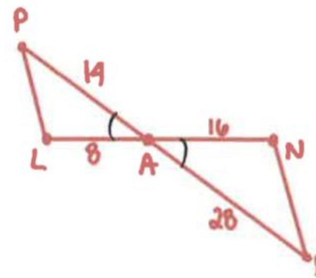
Fill in the blank with *always, sometimes,* or *never.* (2 pts. each)

1. A square and a rectangle are sometimes similar.
2. Congruent polygons are always similar.
3. A trapezoid and a kite are never similar.
4. A rectangle and a square are sometimes similar.
5. Two triangles are sometimes similar.
6. Two circles are always similar.

Determine whether each pair of triangles are congruent. If they are, state the reason why and write a similarity statement. If they are not, write *no*. (5 pts. each)

7.





$\frac{8}{16} = \frac{14}{28}$?

$\frac{1}{2} = \frac{1}{2}$ ✓

yes; SAS~

$\triangle LAP \cong \triangle NAE$

$\frac{18}{21} = \frac{36}{42}$?

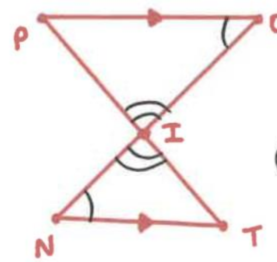
8.

$\frac{6}{7} = \frac{6}{7}$ ✓

yes; SAS~

$\triangle LAG \sim \triangle BRE$

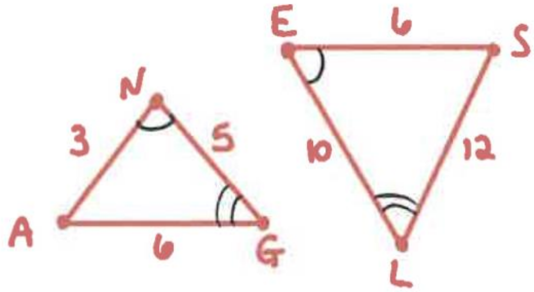
9.



yes; AA~

$\triangle POI \sim \triangle TNI$

10.



$\frac{3}{6} = \frac{5}{10} = \frac{6}{12}$?

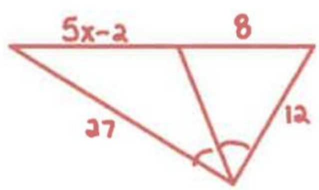
$\frac{1}{2} = \frac{1}{2} = \frac{1}{2}$ ✓

yes; SSS~

$\triangle ANG \sim \triangle SEL$

Solve for the value of x in each of the following problems. (4 pts. each)

11.



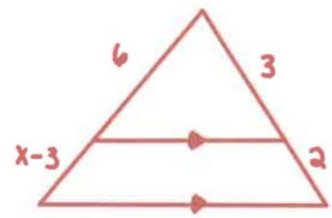
$$\frac{8}{5x-2} = \frac{\cancel{12}\,4}{\cancel{27}\,9}$$

$$20x-8=72$$

$$20x=80$$

$x=4$

12.



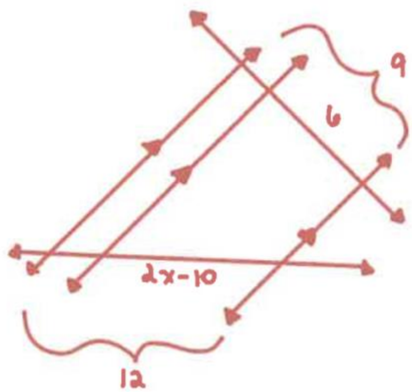
$$\frac{6}{x-3} = \frac{3}{2}$$

$$3x-9=12$$

$$3x=21$$

$x=7$

13.



$$\frac{2\,\cancel{6}}{3\,\cancel{9}} = \frac{2x-10}{12}$$

$$6x-30=24$$

$$6x=54$$

$x=9$

APPENDIX I

THEMES, CATEGORIES, AND CODES

Table I.1 *Corresponding Themes, Categories, and Codes*

Theme	**Category**	**Code**
Theme 1: Struggles With Different Aspects of Math	Frustration and Anxiety	"I've always struggled in math"
		Frustration with memorizing information
		Trying hard doesn't seem to affect grades
		Frustrating when you get problems wrong
		"I don't get it"
		Wrong answers are frustrating
		Struggle with some concepts
		Struggle is so big that technology couldn't help
		New things are always hard
		Low confidence in math ability
	A Dislike of Mathematics	"I hate math"
		Getting problems wrong is stressful
		"I don't like math"
		Math is boring
		Math doesn't make any sense
		Bad relationship with math
		Hard to learn something you're not passionate about
		Bad memories in math
		Math struggles lead to dislike of the subject
		"I don't ever want to learn math"
		Low expectations for math
		Don't like doing math problems
		Not a favorite subject
		"I didn't want to learn geometry"
		"Math is my worst subject ever"
		Geometry has students worried
		Bad expectations for math
	Geometric Proofs are Difficult	Challenging proofs
		Proofs seem undoable on your own
		Proofs aren't the best part of geometry
		Proofs are difficult
		The proofs on IXL were difficult

		No confidence for solving proofs
		Proofs are hard to understand
		Geometry is challenging
		You have to do more than memorize for proofs
	Negative Feelings Toward IXL	Not happy to do IXL
		IXL didn't make student feel more accomplished
		Doubtful about benefiting from IXL
		Bad prior experiences with IXL
		"I don't like IXL"
		"I was not looking forward to it"
		"I thought you were crazy"
		Used a slower process for problem solving in IXL
		Didn't think it would be worth it
		Doubts about using technology for geometry
		Assumed technology would be hard to use
		Technology can be stressful
		Not open to using technology for math
		Technology isn't helpful
		Getting used to technology can be difficult
		Technology makes learning more difficult
		"I try to avoid technology"
		Technology can be uncomfortable to use
		Technology is just another difficult thing in math
		Technology creates more struggles
		Don't like losing points for a wrong answer
		Losing points can be stressful
		Seeing score drop can worsen confidence
		Never getting problems right is frustrating
		IXL can create anxiety
		Geometry isn't a subject for technology
		Technology can be distracting
		Using devices for math is hard
		Technology isn't always reliable
		Can't write on the IXL app
		Using technology makes it hard to concentrate on the math
		Prefer paper and pencil over technology
Theme 2: Positive Outcomes of Using IXL	Changes in Engagement	"I was engaged from the beginning"
		Helping other students is engaging
		IXL problems were engaging
		"I was always engaged with solving problems in IXL"
		Quadrilateral problems were engaging
		IXL helped with engagement
		"The more successful I was, the more engaged I felt"

		Review problems were engaging
		Proofs were engaging
		Using IXL keeps students engaged
		Engagement leads to finishing assignments
		IXL was more engaging than using a book
		Competition with friends was engaging
		Personal competition was engaging
		IXL helped with student focus
	Changes in Motivation	"My motivation for learning geo went up after using IXL"
		Having a score in IXL is motivating
		Motivation increased with IXL
		IXL was more motivating than regular problems
		IXL motivates students to get correct answers
		IXL creates more motivation
		Having a goal in IXL is motivating
		Using iPad for IXL made it more motivating
		Friends were a motivating factor
		No motivation if you don't get immediate feedback
		Being able to finish problems correctly in IXL is motivating
		Long assignments in IXL are less motivating
		Fear of being left out keeps students motivated
		IXL motivated students to learn geometry
	Changes in Confidence	IXL increased confidence with proofs
		Not having to get a perfect score boosted confidence
		IXL boosted confidence in solving problems
		Similar triangle problems increased confidence
		IXL increased confidence overall
		Confidence increased because the problems seemed easier
		IXL helps build confidence
		Getting problems right increases confidence
		IXL helped student confidence with problem solving
		IXL gave problems students felt confident to answer
		Being successful increased confidence
		Students felt they had a better chance of getting IXL problems right
		IXL made regular problems seem easier
		IXL didn't make students feel stupid
		IXL made students feel like they could be successful
		"IXL made it make sense"
		Students could feel themselves being successful with IXL
		"I felt kind of proud of that"

		Not afraid to do problems after IXL
		"Using IXL helped me pass geometry"
		Felt more prepared after using IXL
		Helped students know what to do
		IXL problems seemed easier than expected
		IXL was easier now than before
		Easier than expected to get the hang of IXL
		IXL assignments got easier as you got used to them
		Doing the problems made geometry seem easier
		Learning geometry was easier with IXL
		IXL made understanding geometry easier to do
		Helped students feel confident to learn information
		Students felt like they could tackle the difficult stuff
		Better understanding after using IXL
		Concepts didn't seem as difficult
		Similar triangles made sense after using IXL
		Students felt like they could handle challenging problems
		Gave students confidence to ask questions and help one another
		Students could apply strategies from IXL to problems on tests
		Gave students confidence to be successful on assessments
	Reduced Mathematics Anxiety	"Doing IXL took my anxiety away"
		Students know what to expect with IXL
		IXL changed anxiety over time
		IXL practice helped with test anxiety
		IXL decreased stress levels about math problems
		Not worried about getting IXL problems wrong
		Getting IXL problems right lessened anxiety
		IXL problems were less stressful
		IXL wasn't stressful
		Having immediate help alleviated stress
		IXL lessened anxiety about solving problems
		Not having to get everything right lessened anxiety
		IXL lessened anxiety about assessments
Theme 3: Aspects of Adaptive Learning Environments to Promote Student Learning	Personalized Practice	IXL "felt like it was personalized for me"
		"It kinda gives you a sense of independence"
		Allowed for independent practice
		Working individually on IXL was beneficial
		Personalization of problems was motivating for students
		Students liked doing their own thing
		IXL gave individualized practice

		IXL gave different practice for each student
		Going at your own pace in IXL is beneficial
		Working at own pace was enjoyable for students
		Going at own pace in IXL helped students learn
		IXL gave extra practice for students who wanted it
		The practice in IXL helped students prepare for tests
		Gave different exposure to problems for students
		Practice helps improve problem solving ability
		Practice made it easier to do difficult problems
		Gradually increasing the difficulty level was beneficial
		Students liked how IXL problems slowly got more difficult
		Gradually increasing difficulty level makes it easier to learn
	Explanations	Explanations in IXL were helpful
		Having additional explanations for problems is beneficial
		IXL helps students fix mistakes
		Explanations in IXL helped with anxiety
		Seeing answers helped students who were struggling
		Students used IXL explanations for help with wrong answers
		Students liked it when IXL explained an incorrect answer
		IXL solutions can be used like examples
		Explanations in IXL helped with understanding
		Immediate feedback was helpful to student learning
	Teacher help	Teacher being able to set points was good
		Teacher choosing specific assignments in IXL is good
		Teacher can still help with IXL problems
		Teacher being able to see specific problems allowed help for students
		Teacher seeing work in IXL kept students on task
		Teacher seeing work in IXL kept students engaged
		Teacher seeing IXL practice done at home is helpful
		Motivated because teacher could see work
	Positive Thoughts About Technology	“I think if you can find the right website for your students, it can be helpful”
		IXL became another form of math help
		Gives additional resources for struggling students
		Technology can help when used corrected by teacher and students
		Helps promote student learning

		Gives students a different way to learn something difficult
		Can use technology in conjunction with notes
		Gives students good practice
		Can be helpful for proofs
		Gives good information to students
		Helps students want to learn
		Can help students get better grades on assessments
		Students enjoyed using IXL
		Helps improve student ability to solve problems
		Students can see the usefulness of using technology
		It gives students a fun/enjoyable tool to use
		Shows students that work can be beneficial for them
		Using IXL showed students that using technology in math could be a positive thing