MIDDLE SCHOOL MATHEMATICS, STUDENT GROWTH, AND THE ROLE OF TECHNOLOGY-ASSISTED, INDEPENDENT PRACTICE

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

DOCTOR OF EDUCATION

BY

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BALL STATE UNIVERSITY

MUNCIE, INDIANA

MAY 2019
Acknowledgement

Many individuals have supported my academic endeavors and are deserving of acknowledgement for the role they have played.

I am extremely grateful to my wife, Marisa, for her unwavering patience and support. I began my doctoral studies early on in our marriage and she has been steadfast in providing much needed love and encouragement along the way. The completion of my dissertation would not have been possible without her. I am also thankful to my daughter, Evelyn. Although she is only a year old at the time of this publication, her presence in my life has given me both happiness and motivation.

I would also like to express my deepest appreciation to my committee chairperson, Dr. Joseph McKinney, for his mentorship and guidance. Dr. McKinney was supportive of my research interests and has provided meaningful input throughout the dissertation process. In addition, I would like to thank my committee members, Dr. Lori Boyland, Dr. Nick Elam, and Dr. Karen Ford for their time and involvement. A special thanks to Dr. Serena Salloum for her support and for volunteering her expertise in the field of educational statistics.

I am indebted to the participating teacher for her collaboration in helping conduct the experimental aspects of my study. The teacher invested a significant amount of time working with me and the students to ensure the experiment was carried out with fidelity. She offered detailed feedback that added important background and context to the study.

Finally, I would like to thank my parents, Beverly Arms and Larry Arms, who both spent their entire careers as public educators. They taught me the importance of earning an education and the impact one can make when providing an education to others. From a young age, they instilled in me the belief that learning is about the journey, not the destination.
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Chapter 1 - Introduction

Educational leaders are expected to create and nurture learning environments that enable students to achieve academic success (Robinson, Lloyd, & Rowe, 2008). To meet this expectation, educational leaders collaborate with instructional staff to ensure the effectiveness of their curriculum, instruction, and assessment practices. Successful educational leaders develop relationships with teachers and students that carry great influence (Ogawa & Bossert, 1995).

When student academic deficits are identified, an assessment of the variables that impact learning is necessary. From curriculum programming to environmental factors to the available student supports, all variables are considered when developing a plan to increase learning and improve academic outcomes. When new resources are adopted to address academic deficits, their implementation must be closely monitored to determine if they are yielding the desired results.

This study assessed the influence of technology-assisted, individualized mathematics practice on mathematics proficiency growth in a sample of 7th grade students over a period of 12 weeks. The study’s analysis of technology-assisted, individualized mathematics practice and its effect on mathematics proficiency growth provides educational leaders with a point of reference as they consider how these types of programs are being implemented in their school or school district.

The contents of this chapter include an overview of the problem to be addressed by the study, the purpose of the study, the significance of the study, research questions, the research design, a description of the hypotheses, and the conceptual framework of the study. Delimitations of the study and definitions of key terms are also included. The chapter concludes with a summary of the topics previously identified and a preview of forthcoming chapters.
Background of the Problem

As the global economy evolves due to the increasing prevalence of technology and automation, K-12 schools are under increasing pressure to produce graduates who can solve complex problems and demonstrate proficiency in STEM disciplines (Jang, 2015; Weis et al., 2015). An analysis of 21st century competencies in comparison to workplace data indicate that high quality STEM education is necessary for the United States to be a leader in economic growth (Jang, 2015; National Research Council, 2011; Pea & Collins, 2008). Research from the U.S. Department of Commerce (2011) supports this finding and highlights the importance of STEM workers in the sustainability and growth of the U.S. economy. Policymakers are advocating reforms that increase learning, achievement, and participation in STEM fields (Weis, et al., 2015).

Important to STEM competency is proficiency in mathematics. Those who are mathematically proficient are more competent when thinking critically and problem solving, with numeracy playing an essential role in risk analysis and the evaluation of quantitative information (Burrus, Jackson, Xi, & Steinberg, 2013; Center for Public Education, 2009). K-12 graduates who have acquired proficiency in mathematics are more likely to earn a post-secondary degree, command higher wages, and experience heightened levels of general success and well-being (Center for Public Education, 2009; U.S. Department of Commerce, 2011).

In contrast to the growing need for a mathematically competent population are recent student academic performance trends on standardized assessments. Data from the National Assessment of Educational Progress (NAEP) show that 4th and 8th grade students in the United States performed worse on mathematics assessments in 2015 compared to 2013, with scores from the most recent assessment in 2017 showing little change. From 2013 to 2015 the average
4th grade score declined by two points and the average 8th grade score declined by three points. 4th grade scores remained constant from 2015 to 2017, while 8th grade scores increased by one point (U.S. Department of Education, 2017). Even more alarming, only 40% of 4th grade students and 34% of 8th grade students demonstrated proficiency on the 2017 mathematics assessment (U.S. Department of Education, 2017). When comparing 2015 data representative of the United States students to that of other countries, American students fell from 28th to 35th in mathematics, dropping below the OECD average (OECD, 2017; Stoet & Geary, 2013). Overall, the average mathematics scores for 4th and 8th grade students in 2017 were not significantly different compared to 2015 (U.S. Department of Education, 2017).

With economists sounding an alarm about the gap between STEM education and the required skills in the workplace (Jang, 2015; Lee & Fang, 2009; U.S. Department of Commerce, 2011), along with students’ declining mathematics proficiency rates (OECD, 2017; U.S. Department of Education, 2015; U.S. Department of Education, 2017), many are looking to educational leaders to improve student outcomes (Robinson, 2015; Wagner & Dintersmith, 2015; Zhao, 2015). In general, there is an expectation for K-12 schools to produce creative and innovative thinkers who are prepared for college, the workforce, and society (Pelligrina & Hilton, 2012).

Educational leaders are uniquely positioned to have a direct impact on student outcomes. In a study of high performing schools, teachers reported school leadership to be focused on teaching and learning while actively participating in teacher learning and development (Robinson, et al., 2008). By developing relationships with teachers, educational leaders can significantly influence teaching and learning by helping structure the way teachers do their work (Ogawa & Bossert, 1995). Furthermore, educational leaders have been shown to have a positive
impact on student outcomes when they set a direction for the instructional program and focus on the quality of teaching and learning (Bryk, Sebring, Allensworth, Luppescu, & Easton, 2010; Robinson et al., 2008).

In an effort to direct instructional programming, educational leaders can positively impact student outcomes through the selection of quality teaching resources (Robinson et al., 2008). In an analysis of studies on the influence of leadership on student outcomes, students performed above expected proficiency levels when leadership made appropriate teaching resources available (Robinson et al., 2008). Educational leaders often look to technology-based solutions in hopes they can help address deficits in student proficiency (Slavin & Lake, 2008). The web-based IXL program (www.ixl.com) is one such solution and is a popular resource for mathematics instruction in K-12 schools. Used by as many as one in nine students in the United States (IXL, 2017), IXL is a subscription-based resource that provides opportunities for individualized, adaptive mathematics practice. IXL’s proprietary adaptive platform gives students immediate feedback as they engage in mathematics practice that is progressively difficult. IXL is marketed as a resource for intervention, enrichment, and assessment preparation. When educational leaders consider the academic needs of their students, selecting resources that have been proven to positively impact student learning outcomes is critical.

**Statement of the Problem**

In their quest to meet societal demands and produce mathematically proficient graduates (Jang, 2015; Weis et al., 2015), many schools have adopted the web-based IXL program to help facilitate student practice of mathematics skills. While the relationship between skill practice and competence has been previously studied and deemed positive (Kanive, Nelson, Burns, & Ysseldyke, 2014; Logan, 1988), a lack of research has been cited on the impact of technology-
assisted, independent mathematics practice that is individualized to students’ proficiency levels (Stacy, Cartwright, Arwood, Canfield, & Kloos, 2017). With as many as one in nine students in the United States using the IXL program in some capacity (IXL, 2017), a lack of research on the relationship between use of the program and student outcomes is of concern; evaluating the program’s influence on student learning would be a welcomed supplement to the current body of research on this topic (Slavin & Lake, 2008). The problem this study sought to address was whether student usage of the IXL program to independently practice individualized mathematics skills led to increases in mathematics proficiency growth.

**Purpose of the Study**

The purpose of this study was to determine if a significant difference existed in the mathematics proficiency growth of students who independently practiced individualized mathematics skills using the IXL program for a period of 12 weeks (treatment) compared to students who did not use the IXL program during this period (control). The independent, focal variable in this study was usage of the IXL program to independently practice individualized mathematics skills over the course of 12 weeks in the fall semester of the 2018-2019 academic year. This variable was applied to the treatment group of 51 7th grade students and was monitored by the students’ mathematics teacher during the study. Another group of 46 7th grade students, under the supervision of the same mathematics teacher, was assigned to the control group and did not use the IXL program during the study. The gender (male, female) and lunch program status (free or reduced lunch status, paid lunch status) of the students in the sample were also factored into the analysis as independent, moderator variables.

The dependent variable in this study was pretest to posttest mathematics proficiency growth for students in the sample. The data required to calculate the mathematics proficiency
growth were generated through the fall and winter administration of the Northwest Evaluation Association’s (NWEA) Measures of Academic Progress (MAP) mathematics assessment. The growth between tests was calculated by comparing the difference between students’ mathematics Rasch Unit Scale (RIT) scores from the fall and winter administrations of the assessment.

**Significance of the Study**

This study offers a significant contribution to both research and practice in the fields of mathematics education and educational leadership. Educational leaders are routinely expected to make resources available that improve student outcomes (Robinson et al., 2008). This expectation has not wavered despite budgetary constraints and a student population with increasingly diverse learning needs. Thus, it is critical for educational leaders to adopt curricular resources that have been proven effective in increasing student learning (Slavin & Lake, 2008). The web-based IXL program is a popular option for many schools as a technology-based resource to improve mathematics proficiency (IXL, 2017). This study’s examination of IXL usage and its influence on mathematics proficiency growth provides educational leaders with a point of reference as they consider how the program is being implemented in their school or school district.

While there is considerable research on the topic of technology-mediated instruction and mathematics (Slavin & Lake, 2008), few studies have isolated technology-assisted mathematics practice and its relationship to student learning outcomes (Stacy et al., 2017). Previous research supports the usage of technology-based solutions that provide opportunities for mathematics practice (Bouck & Flanagan, 2009), although most studies have focused only on mathematical computation (Burns, Kanive, & Degrande, 2010; Slavin & Lake, 2008). Through its analysis of the relationship between technology-assisted, independent, individualized mathematics practice
and mathematics proficiency growth, this study contributes to the body of research that seeks to understand how mathematics practice facilitated by technology influences student learning outcomes.

**Research Design**

This study used a quantitative, quasi-experimental research design to determine if there was a statistically significant difference in the mathematics proficiency growth of students who independently practiced individualized mathematics skills using the IXL program for a period of 12 weeks (treatment) compared to students who did not use the IXL program during this period (control). The quasi-experimental design used in this study leveraged a nonequivalent (pretest and posttest) control-group with nonrandom treatment and control group assignment of participants (Creswell, 2005). Following the pretest and posttest, demographic and assessment data were used to conduct a three-way ANOVA with a $2 \times 2 \times 2$ design.

Variables analyzed included independent mathematics practice (experimental group membership), gender (female or male), and student lunch program status (free or reduced lunch status or paid lunch status). The analysis tested the interaction between variables to determine whether the independent focal variable (experimental group membership) had a statistically significant effect on the dependent variable (mathematics proficiency growth rate) and whether the effect was influenced by the value of other independent moderator variables (gender, lunch program status).

**Research Questions**

Two key questions guided my research for this quantitative, quasi-experimental study. These questions were developed based upon research in areas related to mathematics proficiency and learning theory.
1. What influence does technology-assisted, independent mathematics practice that is individualized to each student’s level of proficiency have on mathematics proficiency growth as measured by the NWEA MAP assessment in a sample of 7th grade students?

2. What effect do the moderator variables of gender and lunch program status have on the influence of technology-assisted, independent mathematics practice that is individualized to each student’s level of proficiency and mathematics proficiency growth as measured by the NWEA MAP assessment in a sample of 7th grade students?

**Description of Hypotheses**

The study sought to determine if there were statistically significant differences in the mathematics proficiency growth rates between the fall and winter NWEA MAP mathematics assessments for students in the treatment group compared to students in the control group. A 2 x 2 x 2 experimental design was used to analyze the interaction effect between the independent variables in relation to the dependent variable. By using a multi-factor analysis of variance (three-way ANOVA), the following null hypotheses were tested:

- $H_01$: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group.

- $H_02$: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group students when considering their gender.

- $H_03$: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group students when considering their lunch program status.
H₀₄: There is no significant interaction effect among the variables of experimental group membership, gender, lunch program status, and mathematics proficiency growth.

**Conceptual Framework**

The conceptual framework for this study examined the interaction effect between the three independent variables (focal and moderator) and the dependent variable. Figure 1 provides a visual diagram of the framework, which was developed to test whether use of the IXL program for technology-assisted, independent, individualized mathematics practice by students in the treatment group led to higher rates of mathematics proficiency growth when compared to students in the control group who were not exposed to mathematics skill practice using the IXL program.
Figure 1: Conceptual framework. This figure illustrates the conceptual framework for this study and the variable relationships under review.

The conceptual framework for this study was developed from research in the fields of mathematics proficiency and learning theory and is grounded in Logan’s Theory of Instance Automatization. Logan (1988) found that when students engage in repetitive practice of mathematical skills, both the problems and solutions are programmed into their working memory. As more problems and solutions are added to their working memory, students begin to transition from algorithmic processing to memory-based processing. Through this transition, learners develop automatization when solving mathematical problems and formulas, thus reflecting the development of a domain-specific knowledge base (Logan, 1988).

While previous research has found that computer-based interventions may increase mathematics proficiency (Kanive et al., 2014), studies have identified a deficit in the amount of individualized mathematics practice to which students are exposed (Stacy et al., 2017). The lack of mathematics practice opportunities in K-12 education settings is cause for concern given the body of evidence in support of this practice as a means for increasing competence (Ericsson, Krampe, & Tesch-Romer, 1993; Kanive et al., 2014; Logan, 1988). This conceptual framework was used to determine whether a statistically significant difference existed between the mathematics proficiency growth rates of students who have engaged in independent, individualized mathematics practice using the IXL program and students who have not had the same experience. The effect of the moderator variables of gender and lunch program status on this interaction was also assessed.
Delimitations of the Study

Sample. A convenience, nonrandom sampling method was employed to establish the sample population, consisting of 97 students. A 7th grade mathematics teacher at a middle school in Lafayette, Indiana participated in the study and assisted in facilitating both the treatment and control with her students during the fall semester of the 2018-2019 academic year. The participating school and the student sample were selected due to the moderate level of academic and economic diversity amongst the students, which carries important implications for generalizing the results of the study to a larger population.

The participating teacher led six sections of 7th grade mathematics during the fall semester of the 2018-2019 academic year, with an average class size of 24 students. The teacher met with each section on a daily basis for a 45-minute class period. For the purpose of the study, three of the sections received the treatment while the other three sections did not. For students in the treatment group, interaction with the treatment did not begin until administration of the fall NWEA MAP mathematics assessment had concluded.

Students in both experimental groups received the same curriculum throughout the duration of the study, which was aligned to the Indiana Academic Standards. Classroom instruction and assessment were delivered consistently across all of the teacher’s sections, which included a balance of publisher-created and teacher-created curricular materials. Students in the treatment group had access to a school-issued laptop computer and the IXL program both at school and at home. Students in the control group also had access to a school-issued laptop but did not have access to the IXL program during the study.

Membership in the sample required students to be enrolled in the participating teacher’s mathematics classes for the duration of the study. Participation in the NWEA MAP mathematics
assessment during the fall (pretest) and winter (posttest) administration windows was also a requirement.

**Time of the study.** The study took place during the fall semester of the 2018-2019 academic year, from August of 2018 to January of 2019. This timeframe was selected due to its alignment with the participating school district’s calendar and NWEA assessment windows.

**Location of the study.** The study was conducted in a 7th grade mathematics classroom at a middle school in Lafayette, Indiana. This location was selected based on the demographics of its student population and the assignment of the participating teacher.

**Treatment group – IXL usage plan.** Students assigned to the treatment group followed a prescribed weekly IXL usage plan throughout the duration of the study. During class on the first day of each week, students spent five to ten minutes answering questions in the Continuous Diagnostic area of IXL. Students were required to spend five to ten minutes during each class period the rest of the week practicing the skills assigned to them based on their responses to questions in the Continuous Diagnostic area. By the end of each week, students were expected to have completed approximately 50 minutes of independent skill practice (five to ten minutes of skill practice per day). The skills the students practiced were assigned based on their responses to the diagnostic questions at the beginning of the week, with students’ practice limited to skills that were identified by the program as needing improvement. Students were not permitted to practice skills that had not been assigned to them through the diagnostic questioning. The participating teacher and I monitored students’ practice activity in real-time using the teacher-view tool in the IXL program. At the end of each week, I sent the participating teacher a report for each student showing the amount of time they spent practicing skills, the skills they
practiced, and their SmartScore for each skill. The participating teacher worked with students individually as needed to address any usage concerns that she identified during the study.

**Definition of Terms**

- **Technology-mediated Instruction (TMI)** – Technology programs that diagnose students’ levels of performance and then provide exercises tailored to their individual needs as a means of providing supplemental instruction (Slavin & Lake, 2008).

- **Curriculum** – The means and materials with which students will interact for the purpose of achieving identified educational outcomes (Ebert, Ebert, & Bentley, 2013).

- **Differentiated Instruction** – A philosophy of teaching that is based on the premise that students learn best when their teachers accommodate the differences in their readiness levels, interests, and learning profiles (Tomlinson, 2005).

- **Educational Technology** – The study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources (Januszewski & Molenda, 2013).

- **IXL** – A web-based application that provides adaptive mathematics practice opportunities through unlimited, algorithmically generated questions, real-time analytical reports, and dynamic scoring to encourage mastery (IXL, 2017).

- **Math Growth** – The conditional growth index (CGI), a normative growth metric, is a standardized measure of observed student growth compared to the 2015 NWEA student growth norms. The student growth norms indicate median growth levels for students based on their grade, starting RIT score, the subject in which they tested, and the amount of instructional time between the two tests (NWEA, 2017).
• Math Proficiency – The varying levels of state test performance tied to federal accountability requirements of which NWEA correlates to the RIT scale (Cronin, Dahlin, Adkins, & Kingsbury, 2007).

• NWEA – A research-based, not-for-profit organization that supports students and educators worldwide by creating assessment solutions that precisely measure growth and proficiency – and provide insights to help tailor instruction (NWEA, 2017).

• NWEA MAP Growth Assessment – An adaptive, computerized assessment that measures what students know and informs what they’re ready to learn next. MAP Growth reveals how much growth has occurred between testing events and when combined with norms, shows projected proficiency (NWEA, 2017).

• NWEA RIT Scale – The Rasch Unit Scale (RIT) is a stable, equal interval scale that uses individual item difficulty values to measure student achievement independent of grade level (NWEA, 2017).

• Pedagogy – General teaching practices independent of subject matter (Mishra & Koehler, 2006).

• STEM – An acronym for Science, Technology, Engineering, and Mathematics (Bybee, 2010).

• Technology-assisted Practice – The practice of academic skills and concepts facilitated by technology and digital applications.

Summary

This chapter has outlined the description of the problem addressed by the study, the purpose of the study, the significance of the study, research questions, and the conceptual framework of the study. Delimitations of the study and definitions of key terms were also
included. Subsequent chapters will be dedicated to the review of literature surrounding the topics of the study, specification of the study’s methodology, and the findings of the study.

The next chapter will provide a synopsis of existing research and literature on topics related to the study, such as the role of mathematics in the 21st century economy, recent achievement data, curriculum and pedagogy trends, practice, knowledge acquisition, technology in mathematics education, mathematics assessment, along with theoretical perspectives.
Chapter 2 - Literature Review

“I’m just not very good at math.” This refrain is all too common in school settings and has been voiced in classrooms for as long as they have been in existence. While shying away from mathematics may have been an option for students in previous generations, they can no longer neglect this ever-important discipline (Jang, 2015; National Research Council, 2011; Pea & Collins, 2008). As technological advances change the world at an increasingly rapid pace, demonstrating mathematics proficiency and having the ability to apply mathematical concepts to a variety of situations will be a necessary skill in nearly every line of work (Weis, et al., 2015).

Society has a great responsibility to understand how mathematical knowledge is acquired, how mathematical concepts should be taught, and how mathematics will need to be applied in the future. Educators have long recognized the importance in the practical application of mathematical concepts as a means of acquiring knowledge and achieving proficiency. To this end, flash cards and problem sets have been staples in mathematics classrooms as mechanisms for providing students with opportunities for practice (National Council of Teachers of Mathematics, 1989). The proliferation of computers, tablets, and other digital mediums in school settings has introduced an extensive offering of new options for practicing mathematics (Slavin & Lake, 2008).

The purpose of this chapter is to present a review of literature to synthesize existing research in the field of mathematics education, with a focus on mathematics pedagogy and proficiency. This chapter will be presented thematically, with sections dedicated to the topics of mathematics in the 21st century economy, trends in recent mathematics achievement data, competing mathematics pedagogical approaches, learning theory, utilizing technology as an
instructional tool when teaching mathematics, and strategies for assessing mathematics growth and proficiency.

**The Role of Mathematics in the 21st Century Economy**

Identifying effective methods for increasing mathematics proficiency in K-12 students is paramount for educational leaders (Pellegrina & Hilton, 2012). With STEM-related careers poised to increase at a rapid pace (Jang, 2015; U.S. Department of Commerce, 2011), K-12 schools must invest resources to make certain students possess the knowledge and skills necessary to be successful in this environment (Robinson, et al., 2008). Recent studies have shown that individuals working in STEM-related careers command higher wages than their counterparts in non-STEM careers (U.S. Department of Commerce, 2011). Students who perform well in math at the end of high school have higher future earnings, with a one standard deviation increase in math scores translating into a 12 percent increase in wages (Center for Public Education, 2009). Acquiring a proficient understanding of mathematics is crucial. An inability to apply mathematical concepts will put individuals at increasing risk in the modern world (Jang, 2015; Lee & Fang, 2009; U.S. Department of Commerce, 2015).

STEM proficiency can also be correlated to higher levels of educational attainment, with two-thirds of STEM workers having a bachelor’s degree or higher, compared to just under one-third of other workers (U.S. Department of Commerce, 2011). The Center for Public Education supported this finding: Research indicated students who demonstrate increased levels of mathematics proficiency were more likely to be successful in both higher education and the labor market (2009). Furthermore, studies have shown that numeracy is an important element for decisions involving quantitative information, especially those involving the assessment of risk (Center for Public Education, 2009). Equipping students with STEM-related skills will not only
help in preparing them for the future, it is also vital to our country’s economic growth and stability. Without an adequate supply of STEM-trained individuals, employers may opt to hire employees from other countries or move their businesses to areas of the world more able to meet this demand (Jang, 2015).

Technology continues to bring about fundamental changes to the world’s economy and as a result, the types of skills required to secure gainful employment continue to evolve (Pea & Collins, 2008). Consequently, mathematics proficiency will become increasingly important for success in many career fields. Studies have shown that acquiring STEM-related skills will enable today’s students to thrive in the 21st century economy, as they will achieve a higher standard of living and job security compared to those who lack such skills (Jang, 2015; Lee & Fang, 2009; U.S. Department of Commerce, 2011). With researchers and employers reviewing the current state of mathematics education in the United States and evaluating the proficiency of the future workforce, some believe there is cause for alarm (Robinson, 2015; Zhao, 2015).

**Mathematics Achievement Data**

In analyses of how K-12 schools are addressing STEM competencies in comparison to workplace data, inadequacies in STEM programming were identified, with concern being expressed in the ability of K-12 schools to bridge gaps between education and required workplace skills (Jang, 2015; Weis, et al., 2015). While K-12 schools deliver an extensive mathematics curriculum that addresses a number of detailed learning standards, many critics take issue with the type of mathematical skills students ultimately acquire, citing concerns that they are unable to apply concepts beyond a worksheet or a test given in class (Center for Public Education, 2009).
Recent mathematics achievement data support the assertion that a nationwide deficit in mathematics proficiency exists. The National Assessment of Educational Progress (NAEP) is recognized as an independent indicator of achievement and a consistent measure of academic proficiency. NAEP data show that mathematics scores of 4th and 8th grade students in the United States declined from the 2013 to 2015, with scores from the most recent assessment in 2017 remaining stagnant (U.S. Department of Education, 2017). The average score for 4th grade students declined by two points from 2013 to 2015 and was unchanged in 2017. The average score for 8th grade students declined by three points from 2013 to 2015 and increased by one point in 2017 (U.S. Department of Education, 2017). Overall, the average mathematics scores for 4th and 8th grade students in 2017 were not significantly different compared to 2015 (U.S. Department of Education, 2017).

In terms of proficiency, just 40% of 4th grade students were at or above the proficient level in mathematics in both 2015 and 2017, a decrease from 42% in 2013. 8th grade students fared even worse, with only 33% of students demonstrating mathematics proficiency in 2015 and 34% in 2017, respectively (U.S. Department of Education, 2017). Sixteen states saw declines in 4th grade mathematics scores from 2013 to 2015, while 22 states saw declines in 8th grade mathematics scores. In 2017, 41 states had no significant change in scores, with 10 states declining. Florida and Puerto Rico were the only two states/jurisdictions to see an increase in 4th grade mathematics scores from 2015 to 2017. Florida and the DoDEA (Department of Defense Education Activity) were the only two states/jurisdictions to see an increase in 8th grade mathematics scores from 2015 to 2017 (U.S. Department of Education, 2017).

When comparing the mathematics proficiency of American students to their counterparts from the rest of the world, a downward trend is apparent. The Program for International Student
Assessment (PISA) is a worldwide exam administered every three years to 15-year-old adolescents in 72 countries (OECD, 2017). Data from the last administration of PISA in 2015 show that the average mathematics score for U.S. test-takers decreased 11 points compared to the last time the exam was administered in 2012 (OECD, 2017). When reviewing a comparable sample of countries that participated in the PISA exam in both 2012 and 2015, the U.S. ranking fell from 28th to 35th in mathematics (OECD, 2017), as illustrated in Figure 2.

![Figure 2](image)

*Figure 2.* Combined mean score from the 2015 PISA mathematics assessment. This figure illustrates the combined mean score for male and female PISA test-takers in the United States compared to other countries. Adapted from OECD (2017). PISA 2015 Results (Volume III). Students' Well-Being. Paris: OECD Publishing.

Decreasing levels of mathematics proficiency, as evidenced by data from both NAEP and PISA, should be of concern to education leaders and policymakers at all levels of the K-12 education system in the United States (Tienken & Maher, 2008). The importance of
mathematics in the 21st century stands in contrast to declining achievement data shown across multiple metrics, thus a careful review of mathematics curriculum trends and instructional philosophies may be warranted (National Research Council, 2011).

**Mathematics Curriculum**

Educators have long engaged in debates concerning the most effective mathematics curriculum and have yet to reach a consensus. According to Davison and Mitchell (2008), the prolonged discourse stems from differing philosophical considerations about the nature of mathematics education.

As education reformists have lobbied to increase the rigor in the K-12 curriculum, mathematics has been at the center of the debate (Spillane, 2000). Spillane (2000) found that the mathematics reform movement has attempted to reassess what is considered to be important in the field of study, arguing the understanding of mathematical concepts should take precedent over the memorization of facts and processes.

While mathematics curriculum has been a topic of extensive conversation, Kliebard (1987) indicated there has been little curricular change. This ongoing debate, known as the “Math Wars,” pits the “reformists” against the “traditionalists.” Those in the “reform” camp believe our society is undergoing continual transformation, as opposed to our education system, which tends to be stuck in a reactive mode (Davison & Mitchel, 2009). On the other hand, the “traditionalists” believe the overemphasis on the conceptual understanding of mathematics has been to the detriment of procedural proficiency.

For those in support of reform-based changes in mathematics curriculum, the seminal evidence in support of these ideals came in the form of the *Curriculum and Evaluation Standards for School Mathematics*, released in 1989 by the National Council for Teachers of
Mathematics. The standards introduced a radically new way of approaching mathematics curriculum and, as a result, this new paradigm was soon referred to as “new math.” The standards set forth a constructivist view of mathematics curriculum that focused on what students could do to integrate new knowledge with existing knowledge to bring about a deeper understanding of the content (Stiff, 2001). The authors of the standards highlighted new options technology in mathematics education could afford, in that the burden of calculation was eased, and the methods of solution should therefore change (National Council of Teachers of Mathematics, 1989). The standards emphasized the significance of the qualitative dimensions of children’s thinking, focusing more on understanding than skill. Meanwhile, decreased attention was placed on the rote use of symbols and operations, with a new focus on number sense, estimation, and reasoning. The teaching of thinking skills and the use of calculators for complex calculations in lieu of pencil-and-paper algorithms and memorization of basic facts was encouraged (National Council of Teachers of Mathematics, 1989). The Council denounced the curriculum in some schools that required students to master arithmetic before moving on to a broader curriculum, citing this as a means of denying access to higher mathematics for some students (National Council of Teachers of Mathematics, 1989).

Those in support of the curriculum changes described in the standards continue to support a more principled knowledge of mathematics that focuses on mathematical ideas and concepts rather than predetermined computational steps (Spillane, 2000). In response to critics, reform supporters claim the criticism and subsequent resistance, is borne from the fact that many teachers were taught mathematics differently and are uncomfortable no longer dominating the classroom conversation (Stiff, 2001). Traditionalists are in turn criticized for teaching what they deem important rather than the skills that are required (Jang, 2015).
While the standards presented a fundamental change in how mathematical content should be presented, they were met with swift resistance, as many mathematics educators decried the transition away from memorization, manual calculations, and the recitation of facts. Although the standards, along with other reform-based initiatives that were to follow, prompted policymakers to adopt a more constructivist, standards-based methodology to mathematics curriculum, the mathematics community is still divided. Those critical of the reform-based changes believe the emphasis on conceptual understanding has discounted the importance of computational proficiency, with some researchers hypothesizing that students who have not mastered basic computation fluency are at risk for future difficulties (Axtell, McCallulum, Bell, & Poncy, 2009). Critics of the reform-based curriculum also cite recent mathematics achievement data that point to students having a deficiency in basic computation skills (Musti-Rao & Plati, 2015).

In a 2008 statement, the National Mathematics Advisory Panel (NMAP) derided the ongoing debate regarding the relative importance of conceptual knowledge versus procedural skills, calling the conflict misguided, and defining both criteria as necessary for effective and efficient problem solving (Kanine et al., 2014). While the merits of the constructivist reform efforts are still up for debate, they have brought about change in how mathematics content is presented in schools throughout the country. Drill has fallen out of favor, along with memorization and busy-work, with more of a focus on didactics rather than math practice (Stacy et al., 2017). Although intense focus has been placed on curricular topics and the type of mathematics content presented to students, often overlooked are the instructional strategies in use and the way the curriculum is delivered.
Mathematics Pedagogy

While the debate about mathematics reform has focused primarily on curriculum, minimal attention has been given to the importance of professional development and instruction (Slavin & Lake, 2008). Despite the ongoing rhetoric about new and innovative curriculum approaches, research by Lake and Slavin (2008) showed a lack of evidence supporting the importance of curriculum choices. Through their review of effective programs in elementary mathematics, it was determined that the key to improving mathematics achievement outcomes is changing the way teachers and students interact in the classroom (Slavin & Lake, 2008). In their study of elementary mathematics proficiency Fuchs, Fuchs, and Karns (2001) identified a direct link between proficiency and the quality of instruction students receive at the elementary level. Although researchers have not advocated for the delivery a weak curriculum lacking in cohesiveness and rigor, K-12 schools should resist overemphasizing the role of curriculum to the detriment of pedagogy and instructional practice. As Simon noted, “the ingredient necessary in order to initiate mathematics learning is pedagogy” (1995).

When teaching mathematics, classrooms typically include a population of students who present a broad spectrum of knowledge and skills. Despite this challenge, the unwavering goal is to bring about mathematics proficiency, which Kilpatrick, Swafford, and Findell (2001) described as a conceptual understanding, procedural fluency, the ability to formulate and mentally represent problems, and reasoning. In considering the best options for supporting mathematics proficiency and reflecting upon the varying mathematical skills students in each classroom may possess, research highlights the ongoing challenge of differentiating instruction to meet the diverse needs of students (Poncy, Fontanelle, & Skinner, 2013). To confront this challenge, teachers must become skilled practitioners who understand how to match instruction
to the individual needs of the learner while balancing their time and resources (Cates, 2005). Ames (1992) recommended teachers evaluate the individual needs of their students to ensure learning objectives, instructional levels, and learning activities are in alignment, as the way students are engaged can either facilitate or hinder their learning.

Current pedagogical approaches tend to give preference to instructional tasks that allow students to evaluate multiple options to construct their own understanding of a concept or principle. While repetitive practice has fallen out of favor in some circles, research has shown that students are taught how to become automatic through the provision of drill and practice (Tournaki, 2003). Moreover, providing students with practice opportunities learning mathematics has been identified by Binder (1996) as a key ingredient in computational fluency. Studies have shown that computational fluency, which Logan, Taylor, and Etherton (1996) referred to as “the ability to solve math problems quickly by recalling the answer rather than performing the necessary mental algorithm,” (p. 184) enables students to avoid devoting much cognitive energy to the computational task. The cognitive energy students would have devoted to the computational task can instead be dedicated to more advanced applications within the problem (Burns et al., 2010). In their justification for inclusion of practice opportunities as an instructional strategy, Szadokierski and Burns (2008) argued that the amount of repetition is the instructional variable most closely related to retention of newly learned material.

There is a natural tendency to associate practice with the memorization of mathematical facts and, subsequently, computational fluency. However, research by Stacy et al. (2017) points to a relationship between individual practice and the proficiency of mathematical concepts beyond those related to computation. Through their research on the use of technology to support informal mathematics practice, the authors argued that teachers and students are taking the
wrong approach to mathematics practice and referred to a “math practice gap.” The tendency for students to rarely practice mathematics outside of school requirements (2017). Commonplace is the scenario wherein student practice occurs only after the teacher has presented a lesson on a concept. In this situation, most students in the classroom practice the same skill, using the same prescribed problem sets, which typically come in the form of a worksheet or practice problems from the textbook. Given the likelihood students’ mathematics skills varying widely, requiring them all to complete the same practice exercises has the potential to present some students with concepts above their competence level and other students with concepts in which they are already proficient. This model often results in a negative experience for all students (Stacy et al., 2017).

Stacy et al. (2017) questioned why there is no general call for students to practice mathematics at their own level. The concept of only practicing mathematics when problems or homework are assigned is very different compared to reading, where students are encouraged to practice independently at every opportunity. Stacy et al. (2017) posited that at the elementary level, mathematics requires more “mind skills” than reading, therefore mathematics competence depends crucially on practice, even more so than reading competence does. Central to their argument was that mathematics practice needed to be interactive and individualized, thus providing students with a sustained positive experience.

Additional research has further supported the notion that practice should play a prominent role in mathematics education. Although Haring and Eaton (1978) found that a student must first complete the skill somewhat accurately before engaging in independent practice, they determined that sustained, independent practice may lead to improved outcomes and higher levels of mathematics proficiency. In a 2011 study conducted by Kucian et al., evidence showed
that eight to ten-year-old students who practiced mathematics at home for 15 minutes a day, five
days a week, for five weeks, showed improved performance compared to their peers who did not
engage in the same practice routines. This finding supports the notion that independent
mathematics practice, sustained over an extended period, leads to improvements in students’
mathematics proficiency.

Research by Slavin and Lake (2008), along with many others, reinforces the notion that
pedagogy is more important than curricular considerations in producing improved student
outcomes. When reflecting on how to improve mathematical proficiency, K-12 schools should
consider how to better support teachers in improving and enhancing their instructional practice
rather than emphasizing the adoption of new curricular resources (Slavin & Lake, 2008). While
pedagogical approaches used in the classroom must be aligned to the needs of the students,
teachers should be cognizant of the role meaningful practice should play in mathematics
instruction (Kucian, et al., 2011). Additional research related to practice and knowledge
acquisition will be presented in the next section of this review.

**Theoretical Perspectives**

Although constructivist mathematics reforms have provided educators with useful ways
to consider learning and learners, redesigning mathematics pedagogy, while balancing the need
to still integrate certain behaviorist principles, is a considerable challenge (Simon, 1995). Due to
the adoption of standards-based curricula throughout the country, the impetus to adopt
constructivist perspectives and implement reform ideas has been strong. Despite widespread
adoption and implementation, many mathematics educators are still struggling to adhere to the
demands to integrate more constructivist principles into their instruction while still attempting to
provide students with repetition and practice opportunities. Considerable debate continues as to
whether teachers should practice behaviorism, the dispensing of information through direct instruction or constructivism, the practice of being facilitators of learning (Weegar & Pacis, 2012), or a combination of the two.

Romberg (2010) identified the dominant psychological notions about the learning of mathematics to be based on behaviorism, with a focus on the learning outcomes rather than how learning occurs, and an emphasis on drill and practice routines. Where constructivists believe that knowledge is developed through active participation in learning and therefore help students see relevance and meaningfulness in what they are learning, behaviorists are not interested in what might occur in people’s minds; their only interest is in behavioral (learning) responses (Weegar & Pacis, 2012). According to Weegar and Pacis (2012), behaviorism in education settings relies on extrinsic motivators such as grades, prizes, privileges, recognitions, and praises to ensure the replication of the learned activity or behavior. Rather than involving students in the learning process, behaviorists utilize direct instruction and assess learning based on responses on tests (Weegar & Pacis, 2012). In terms of behaviorism in mathematics education, Shield (2000) described behaviorists as being of the belief that students learn by memorizing chunks of information before higher-level, problem-based learning can occur.

Educational technology, which continues to play a growing role in K-12 education, traces its roots to behaviorism with Skinner’s teaching machine (Weegar & Pacis, 2012). Weegar compared Skinner’s teaching machine to many instructional software applications in use by students today, as they rely on the reinforcement of behavior by awarding prizes, games, or other incentives (2012). The early work of Robert Gagne gave special attention to drill and practice, which is consistent with the content provided in many instructional software applications (Weegar & Pacis, 2012). The drill and practice tutorials inherent to many instructional software
applications are also designed to reward students through encouraging feedback before they progress to the next level or objective (Shield, 2000).

**Conceptual Framework**

The conceptual framework for this study examined the interaction effect between the three independent variables (focal and moderator) and the dependent variable. Figure 1 provides a visual diagram of the framework, which was developed to test whether use of the IXL program for technology-assisted, independent, individualized mathematics practice by students in the treatment group led to higher rates of mathematics proficiency growth when compared to students in the control group who were not exposed to mathematics skill practice using the IXL program.

The conceptual framework for this study was developed from research in the fields of mathematics proficiency and learning theory and is grounded in Logan’s Theory of Instance Automatization. Logan (1988) found that when students engage in repetitive practice of mathematical skills, both the problems and solutions are added to their working memory. As more problems and solutions are programmed into their working memory, students begin to transition from algorithmic processing to memory-based processing. Through this transition, learners develop automatization when solving mathematical problems and formulas, thus reflecting the development of a domain-specific knowledge base (Logan, 1988).

While previous research has found that computer-based interventions may increase mathematics proficiency (Kanive et al., 2014), studies have identified a deficit in the amount of individualized mathematics practice to which students are exposed (Stacy et al., 2017). The lack of mathematics practice opportunities in K-12 education settings is cause for concern given the body of evidence in support of this practice as a means for increasing competence (Ericsson,
Krampe, & Tesch-Romer, 1993; Kanive et al., 2014; Logan, 1988). This conceptual framework was used to determine whether a statistically significant difference existed between the mathematics proficiency growth rates of students who have engaged in independent, individualized mathematics practice using the IXL program and students who have not had the same experience. The effect of the moderator variables of gender and lunch program status on this interaction was also assessed.

Kanive et al. (2014) defined the importance of practice as well known: No matter the skill, practice is likely to benefit competence. While practice may in fact lead to increased competence, the relationship between practice, motivation, and effort cannot be overstated; the most cited condition for optimal learning and improvement of performance is the subjects’ motivation to attend to the task and exert effort to improve. Research on practice and knowledge acquisition further indicates that in order for practice to yield results, feedback must be both immediate and informative, and subjects should have the opportunity to repeatedly perform similar tasks (Ericsson et al., 1993).

In considering how practice influences knowledge acquisition in the field of mathematics and education, Van de Walle, Karp, and Bay-Williams (2006) supported previous research by Haring and Eaton (1978) in that the suitability of practice is dependent upon whether meaningful concepts have been previously developed. Furthermore, Burns, Klingbell, and Ysseldyke (2010) found that students demonstrate higher academic achievement when independent practice is provided at each student’s appropriate level. This finding aligns with the argument made by Stacy et al. (2017) that practice should be individualized and instructionally appropriate. To provide individualized practice that is instructionally appropriate, teachers must guide students through their learning and direct them toward optimal practice activities (Ericsson et al., 1993).
Individualizing practice for a classroom of students with diverse needs is no easy feat. Although large-group mathematics practice, wherein students are applying concepts to a consistent problem set, is ubiquitous across K-12 schools, research has shown that individualized practice is far superior (Ericsson et al., 1993). Due to the inherent challenges in organizing and delivering individualized practice to a diverse classroom of students, instructional software applications that align practice activities to the learning needs of individual students have become increasingly appealing to K-12 schools (Stacy, et al., 2017).

Regardless of the delivery mechanism, the end result of sustained practice in most fields tends to be automaticity. Tronsky’s (2005) research showed that over time, automation becomes the dominant mental strategy because it yields the highest accuracy rates and shortest response times. Tronsky’s earlier research with Royer (2002) found that practicing skills in order to automatize them reduces working memory load, which, according to Sweller (1988), is necessary for the construction of new conceptual knowledge. In a study comparing the effects of computer-based practice compared to conceptual interventions on mathematics fact retention and generalization, Kanive et al. (2014) determined that learning a skill through practice emphasizes both accuracy and automaticity in mathematics, which resulted in higher mean scores on a generalization measure.

Practice activities have the potential to increase proficiency, improve performance, and enhance understanding, so long as they are structured in an appropriate manner and individualized to the needs of each learner (Stacy, et al., 2017). While assigning a group of students the same practice problems for mathematics homework is not likely to yield improved mathematics proficiency, providing students with individualized practice opportunities may hold promise. Previous research on the role of practice and knowledge acquisition indicates a strong
relationship between practice and automation, which can improve processing speed, reduce memory workload, and facilitate the construction of new conceptual knowledge. As schools consider how to provide students with opportunities for individualized mathematics practice, they often turn to technology (Slavin & Lake, 2008). With the advent of personalized computing and the proliferation of digital resources, the application of educational technology may provide options for facilitating the type of individualized practice many researchers have deemed important.

**Technology and Mathematics Education**

In the past decade technology, in the form of various instructional software applications, has been marketed as the cure for education’s ills. With the prevalence of online learning, virtual charter schools, and even online preschool, there is no shortage of examples as to how technology has pervaded the field of education. While technology and digital resources can be easily integrated in many content areas, mathematics has always been somewhat of a challenge. At the heart of most mathematics classrooms is the “math notebook,” or some other forum that allows students to complete mathematical exercises using pencil and paper. Although technology has provided new ways to deliver content and provide opportunities for practice, moving away from paper and pencil has been a challenge for many mathematics teachers. In reviewing research related to technology use in mathematics classrooms, identifying challenges and problems with implementation was not difficult.

According to Anthony and Clark (2011), the lack of technology integration in mathematics classrooms is due to misalignment between curricular goals, instructional resources, conceptualizations of technology, and technology planning decisions. While many schools have introduced ubiquitous computing (providing each student with a device) as a conduit for
instructional change, multiple dilemmas have surfaced that have been a detriment to the desired changes. Research has found that mathematics teachers struggle to understand the perceived use of the technology within the classroom, have difficulty determining technology’s role in the activity, and lack an understanding of specific strategies that could be used to achieve their instructional goals (Anthony & Clark, 2011). Through his research, Cates (2005) identified similar challenges, and expressed the sentiment that teachers are continuously bombarded with new educational technologies aimed at facilitating educational progress of students.

Despite these implementation challenges, proponents of using technology to teach mathematics have pointed to studies that indicate computers and calculators can support and enhance problem solving environments, decrease the time required to master skills, and allow more time to be spent on conceptual understanding (Hardman, 2005).

To further isolate this review of technology and mathematics education, the focus will now pivot to two specific types of technology usage: technology-mediated instruction (TMI) and technology-assisted practice (TAP).

**Technology-mediated Instruction (TMI)**

Technology applications defined as technology-mediated instruction typically present both content and instruction to students. In many environments, TMI applications are used for remediation and enrichment purposes. In other cases, such as credit recovery classrooms, they serve as the primary means of delivering the curriculum to students. Many TMI applications involve some form of a baseline assessment, which students must take before they are able to utilize the application. Results of the baseline assessment are typically used to automatically assign instruction to students based on their level of performance on the baseline assessment.
In an analysis of effective programs in elementary mathematics, many studies were cited that showed substantial positive effects of using TMI, especially for skills related to computation (Slavin & Lake, 2008). Further research is warranted to determine if the positive effects in computation were the result of drill and practice exercises embedded within the instructional activities. If this is the case, future research might choose to explicitly define these exercises as technology-assisted practice (TAP) to prevent misinterpretation as to the effectiveness of TMI applications.

Additional studies on TMI and mathematics proficiency tend to support Slavin and Lake’s findings (2008) that computer-based interventions can increase mathematics skills. The research conducted by Kanive et al. (2014) produced similar findings in support of TMI. In their comparison of computer-based practice to conceptual interventions, they found that students assigned to the computer-based intervention showed a greater increase in retention scores than students assigned to the control group. Furthermore, they summarized their research by stating that “computer-based interventions may prove to incorporate instructional strategies identified as essential elements to the development of mathematics proficiency without expanding the limited time and resources in schools that are required for other evidence-based interventions” (2013, p. 87).

While the findings referenced above certainly appear promising for TMI and mathematics education, further research is likely warranted to determine if the positive relationship is isolated to drill and practice activities and to evaluate whether or not TMI options would be beneficial for broader instructional use cases.
Technology-assisted Practice (TAP)

The decision to separate the research on technology-mediated instruction and technology-assisted practice was deliberate. While technology-mediated instruction seeks to teach students content and deliver curriculum (e.g. provide instruction), technology-assisted practice resources provide students with opportunities for guided, often individualized skill practice. Technology-assisted practice applications would not be utilized to teach new concepts to students, nor would they be used to remediate or enrich students on concepts they have failed to learn or have yet to learn. Technology-assisted practice applications are precise in their purpose, in that they serve to provide options for the individualized practice of concepts and skills to which students have already been exposed.

In Louw, Muller, and Tredoux’s (2008) study of time-on-task, technology, and mathematics achievement, a correlational analysis was conducted to assess the relationship between improvement in mathematics and the amount of time spent on a technology-assisted practice application. The analyses revealed a positive relationship between the amounts of time spent practicing within the application and improvement in mathematics. While their research indicated a positive relationship between TAP and mathematics proficiency, they identified a need for further study to determine if a higher amount of time spent using the application resulted in further improvements in mathematics proficiency, and thus an even stronger relationship.

In a 2008 study, the National Mathematics Advisory Panel endorsed “technology-based drill and practice” as improving students’ performance in specific areas of mathematics, such as computation. Meanwhile, Bouck and Flanagan (2009) recommended technology as a viable
instructional method for teaching mathematics due to the practice opportunities it can provide, which could potentially contribute to higher levels of mathematics proficiency.

Subsequent research has identified a desire by educators to have TAP applications that can be made available to a large group of students while simultaneously differentiating the type of practice by providing an appropriate level of challenge for each student (Musti-Rao & Plati, 2015). This desire is in alignment with the prior recommendations made by Stacy et al. (2017), which promote the use of TAP applications for individualized, independent mathematics practice.

Technology-assisted practice, although similar in some ways to technology-mediated instruction, serves a different purpose: its primary objective is to provide practice, not instruction. Research has indicated a positive relationship between TAP applications and mathematics proficiency, especially in computation (Musti-Rao & Plati, 2015). Further study is warranted to assess the strength of the relationship, to determine whether the relationship is consistent across all demographic subgroups, and to evaluate the strength (or existence) of the relationship in areas of mathematics other than computation.

**Assessing Mathematics Growth and Proficiency**

While K-12 schools invest a great deal of time and resources to analyze the mathematics curriculum they deliver to their students, along with the pedagogical approaches used to facilitate this delivery, understanding how to effectively assess student learning is equally critical. Educators use assessments to answer educational questions with data. For the past century, K-12 achievement testing has been designed to assess student proficiency of content domains based on how the domain is organized into grade-specific units (Kingsbury & Hauser, 2004). This fixed-form assessment model is based on constructing a test for a defined grade level and
administering the test to all students in the grade level. These tests are typically summative in nature, occurring on a yearly basis.

Fixed-form assessments provide for ease of use and strict control of the content seen by each student (Kingsbury & Hauser, 2004); however, they tend to prioritize the identification of discrepancies between student performance and predetermined proficiency levels. As higher standards make proficiency harder to achieve, it is likely that more students will be labeled as “below proficient.” Fixed-form assessments are often used to make decisions concerning the placement of students into categories. Although educators may deem this to be an effective method for sorting students based on their test performance, the data provided by the fixed-form assessments may not be appropriate for making instructional decisions or for measuring student growth (Kingsbury & Hauser, 2004).

An increasingly diverse student population, coupled with rapid changes in technology, has caused many educators to reconsider what is taught, when and how it is taught, and how students are expected to demonstrate their knowledge and skill. Because of these changes, educators have begun to rethink what is assessed, how the information is obtained, and how it integrates back into the educational process (Brown, Hine, & Pellegrino, 2008). Just as technology has provided educators with new ways to deliver curriculum and facilitate meaningful practice, it has also brought about new methods for administering formative assessments and acquiring data in a timely, usable format (Chudowsky, Glaser, & Pellegrino, 2004). Studies have shown that technology removes some of the constraints that previously made high-quality formative assessment difficult or impractical for classroom teachers (Brown et al., 2008).
As many K-12 schools have acquired greater access to technology, they have turned to computerized adaptive tests (CAT) to obtain a precise measure of the instructional level of each student (Brown et al., 2008). Unlike fixed-form tests that assess students based on predetermined grade-level proficiencies, computerized adaptive tests provide teachers with a more accurate representation of each student’s instructional level. In an adaptive test, items are selected for administration from a large pool of test questions. The difficulty of the test items presented to students depends on their performance on previously presented test items (Kingsbury & Hauser, 2004). When students answer a test item correctly, they are presented with a more challenging test item. When students answer a test item incorrectly, they are presented with an easier test item. The adaptive presentation of test items based on student response allows the test to determine the exact instructional level of each student. Weiss (1982) cited the advantages of this adaptive-testing model to include increased testing efficiency, and tests that are challenging to students but not frustrating. In their analysis of testing models, Kingsbury and Hauser (2004) determined adaptive tests provided more information at every level of achievement compared to fixed-form tests.

In 1973, a not-for-profit educational services organization called the Northwest Evaluation Association (NWEA) was formed. NWEA’s goal was to develop a precise way to measure an individual student’s academic growth. Since the year 2000, NWEA has produced a computerized adaptive assessment known as the Measures of Academic Progress (MAP). MAP tests are now customized for each state and are aligned to specific state standards for students in grades K-10 (Wang, Mccall, Jiao, & Harris, 2013). Furthermore, NWEA utilizes anonymous assessment data from over 10.2 million students to create national norms, placing students and schools within a representative sample.
Like most computerized adaptive tests, the NWEA MAP tests use a unidimensional item response theory (IRT) model known as the Rasch Unit Scale, which is based on the premise that correlations among responses to test questions can be explained by a single underlying trait (Wang et al., 2013). The Rasch Unit Scale is used by NWEA to represent student performance and was conceived by the Danish mathematician Georg Rasch (NWEA, 2017). The Rasch model is used extensively in assessment in education, particularly for skill attainment and cognitive assessments.

The NWEA MAP mathematics test has proven to be an accurate method for measuring both the proficiency level and academic growth rate of individual students. The MAP mathematics test consists of seven domains: Number/Numeration Systems, Operations/Computation, Equations/Numerals, Geometry, Measurement, Problem-Solving, Statistics/Probability, and Applications (Wang et al., 2013). Test items are drawn from a bank of 15,000 that have been field tested, screened for bias and sensitivity issues, statistical qualities, and are calibrated for difficulty using Rasch modeling. On a periodic basis, NWEA conducts both reliability and validity studies to assess the qualities of the MAP tests. (Brown et al., 2008).

Once a student completes the MAP test a scale score, known as the RIT score, is generated for each domain. The RIT scales are stable, equal interval scales that use individual item difficulty values to measure student achievement independent of grade level. An advantage to the RIT score is that it has the same meaning regardless of the grade or age of the student (NWEA, 2017). The RIT scores produced by the MAP tests measure a student’s level of achievement in a subject.

Administering the NWEA MAP mathematics test as a formative assessment tool can provide educators with meaningful information about a student’s individual proficiency level and
their rate of academic growth. Unlike fixed-form tests, which compare student performance to a predetermined proficiency level, computer adaptive tests, such as the MAP test, take advantage of technology to generate a precise measure of student proficiency. The data provided by the MAP tests can then be utilized by teachers to modify their pedagogy in such a way as to provide students with personalized instruction and individualized opportunities for independent practice.

**Gender and Academic Achievement**

An enduring assumption exists that females are not attracted to STEM fields and that female students are outperformed by their male counterparts in those subjects during school years. Current research on this topic calls into question the notion that male students have a greater aptitude for mathematics and science concepts than female students. A recent review of international data (PISA) determined that in 70% of the world’s countries, females outperform males in academic achievement independent of other factors such as gender equality, politics, and economics (Stoet & Geary, 2015). The study went on to describe that females tend to outperform males in reading, mathematics, and science by the age of 15, regardless of political, social, or gender equality issues and policies found in their home country (Stoet & Geary, 2015).

In countries such as the United Kingdom and the United States, however, the academic achievement of boys and girls was similar (Stoet & Geary, 2015). With respect to mathematics achievement, recent NAEP data show male and female students demonstrate similar proficiency levels. Results from the 2017 assessment show 4th grade male students outperformed their female counterparts by only two points, while 8th grade male students outperformed their female counterparts by only one point (U.S. Department of Education, 2017).

Despite male and female students in the United States having similar academic proficiency levels according to PISA and NAEP statistics, other indicators reveal a potential
disparity growing between the two genders. According to statistics made available by the U.S. Department of Education, women comprise more than 56% of students on college campuses nationwide, with 2.2 million fewer men than women enrolling in college in the 2017 academic year (U.S. Department of Education, 2017). An analysis of grade point average (GPA) trends for high school students shows an increasing gender gap, with female students consistently achieving a higher GPA than male students (Fortin, Oreopoulos, & Phipps, 2015). The study, which sought to better understand this growing gender gap, found the predominance of females at the top of the GPA distribution can be attributed to their higher educational expectations and plans to pursue a college degree (Fortin et al., 2015). The study concludes by highlighting the role of students’ motivation and gender differences; among 8th grade male students, a dominant factor accounting for lower grades was a measure of the frequency of having been sent to the office or to detention over the previous year, thus suggesting a correlation between motivation, misbehavior, and academic achievement (Fortin et al., 2015).

**Summary**

This chapter provided a review of literature on topics related to mathematics proficiency. Increasing mathematics proficiency is an urgent challenge K-12 schools must work to address (Jang, 2015; Weis et al., 2015). With the global economy growing increasingly reliant on technology and the corresponding STEM fields, students must be equipped with the mathematical proficiency necessary to enter the 21st century workforce (Jang, 2015; National Research Council, 2011; Pea & Collins, 2008). With recent achievement data indicating decreases in mathematics proficiency levels (OECD, 2017; Stoet & Geary, 2013; U.S. Department of Education, 2017). K-12 schools must refocus their efforts on instructional
practices that have been shown to increase mathematics proficiency and improve student outcomes (Slavin & Lake, 2008).

While a great deal of debate has taken place surrounding the reform of the mathematics curriculum (Kanive, et al., 2014), recent studies have shown this dialogue to be less than impactful (Slavin & Lake, 2008). Research indicates the most important component to increasing mathematics proficiency is the interaction between the teacher and students (Slavin & Lake, 2008). The research encourages educational leaders to ensure their energy and resources are focused on initiatives that have been shown to improve student learning. Specifically, educational leaders should continue to invest in teacher professional development efforts, as improving the manner in which they design and deliver instruction has a direct correlation to the level of mathematics proficiency attained by their students (Slavin & Lake, 2008).

Skilled teachers understand how to strike a balance between theoretical approaches, know when to utilize constructivism to engage students in reflective learning, and when to integrate behaviorism to support automaticity and process knowledge (Weegar & Pacis, 2012). When designing instructional activities, teachers should consider the most effective manner for providing individualized practice opportunities for their students, as research has indicated the importance of independent, developmentally appropriate practice in the acquisition of knowledge and skills (Louw et al., 2008).

Educational technology has accelerated the rate of change in many school settings and has the potential to dramatically enhance the teaching and learning process through uses of technology-mediated instruction and technology-assisted practice. Technology-mediated instruction has been shown to support mathematics proficiency in a variety of research studies (Slavin & Lake, 2008). Technology-assisted practice has also proven to be effective in helping
students acquire mathematical skills, especially as they relate to computation (National Mathematics Advisory Panel, 2008). In addition to providing new instructional options, technology has also enabled schools to leverage computerized adaptive tests such as the NWEA MAP assessment. Computerized adaptive tests provide educators with precise data regarding a student’s individual proficiency level and their rate of academic growth, information that is necessary to design and deliver individualized instructional programs (Brown et al., 2008).

Further research is warranted in several of the areas analyzed in this review. Attention has been called to the lack of research regarding the extent to which mathematics competence depends on informal mathematics practice (Stacy et al., 2017). The dearth of research in this area stands in sharp contrast to the abundance of research on informal reading practice. While many of the studies analyzed by Slavin and Lake (2008) showed a positive relationship between TMI and mathematics proficiency, the field would benefit from further research to evaluate whether these results hold true across all demographic subgroups and whether the same relationship exists in mathematical areas other than computation. In the next chapter, the methodological approaches utilized for this research study will be addressed in detail.

The next chapter describes the methods that were used to understand the influence of technology-assisted, individualized mathematics practice on mathematics proficiency growth in this study. The research questions and hypotheses are presented, along with a discussion surrounding the selected research design. The defense for using a quantitative analysis is offered and the methods used to present the results are described. The sample population, instrumentation, design of the experiment, and general limitations of the study are also reviewed at length.
Chapter 3 - Methods

There is a plethora of curricular materials, technology programs, and instructional strategies to utilize when teaching mathematics. Despite few independent studies that assess their effectiveness, each resource is sold with promises of improved student outcomes. Schools subsequently invest time, energy, and funding to make new resources available. Rather than taking a research-based approach, there is a tendency to employ a myriad of instructional resources with the hope that one, or a combination of many, will bring about increases in student learning. Given the concerning trend of decreasing mathematics proficiency levels (OECD, 2017; Stoet & Geary, 2013; U.S. Department of Education, 2017), it is incumbent upon educational leaders to evaluate the effectiveness of the curricular resources and instructional strategies used by their teachers to ensure student learning goals are met.

This chapter describes the methods that were used to understand the influence of technology-assisted, individualized mathematics practice on mathematics proficiency growth in this study. The research questions and hypotheses are presented, followed by a discussion of the research design. The rationale for using a quantitative analysis is provided and the methods used to present the results are described. The sample population, instrumentation, and the design of the experiment are then reviewed at length. The chapter concludes with a summary of the general limitations of the study.

Research Questions

Two key questions guided my research for this quantitative, quasi-experimental study. These questions were developed based upon research in areas related to mathematics proficiency and learning theory.
1. What influence does technology-assisted, independent mathematics practice that is individualized to each student’s level of proficiency have on mathematics proficiency growth as measured by the NWEA MAP assessment in a sample of 7th grade students?

2. What effect do the moderator variables of gender and lunch program status have on the influence of technology-assisted, independent mathematics practice that is individualized to each student’s level of proficiency and mathematics proficiency growth as measured by the NWEA MAP assessment in a sample of 7th grade students?

Description of Hypotheses

The study sought to determine if there were statistically significant differences in the mathematics proficiency growth rates between the fall and winter NWEA MAP mathematics assessments for students in the treatment group compared to students in the control group. A 2 x 2 x 2 experimental design was used to analyze the interaction effect between the independent variables in relation to the dependent variable.

- Students assigned to the treatment group
- Students assigned to the control group
- Students with a lunch program status of free or reduced lunch
- Students with a lunch program status of paid lunch
- Students of the female gender
- Students of the male gender

By using a multi-factor analysis of variance (three-way ANOVA), the following null hypotheses were tested:

H₀₁: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group.
H₀₂: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group when considering their gender.

H₀₃: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group when considering their lunch program status.

H₀₄: There is no significant interaction effect among the variables of experimental group membership, gender, lunch program status, and mathematics proficiency growth.

**Research Design**

This study used a quantitative, quasi-experimental research design to determine if there was a statistically significant difference in the mathematics proficiency growth of students who independently practiced individualized mathematics skills using the IXL program for a period of 12 weeks (treatment) compared to students who did not use the IXL program during this period (control). The quasi-experimental design used in this study leveraged a nonequivalent (pretest and posttest) control-group with nonrandom treatment and control group assignment of participants (Creswell, 2005). Following the pretest and posttest, demographic and assessment data were used to conduct a three-way ANOVA with a 2 x 2 x 2 design. Variables analyzed included independent mathematics practice (experimental group membership), gender (female or male), and student lunch program status (free or reduced lunch status or paid lunch status). The analysis tested the interaction between variables to determine whether the independent focal variable (experimental group membership) had a statistically significant effect on the dependent variable (mathematics proficiency growth rate) and whether the effect was influenced by the value of other independent moderator variables (gender, lunch program status).
Quantitative studies are appropriate for exploring causal relationships between variables (Creswell, 2004; Neuman, 2003). To that end, a quasi-experimental research design was selected for this study to isolate and define the variables and variable categories as identified by the hypotheses (Brannen, 2017). The study utilized a multi-factor analysis of variance to examine the interaction effect of three independent variables on a single dependent variable (Cardinal & Aitken, 2013). An advantage to using this particular statistical test was that it allowed for the control of within- and between-group variation, which accounted for the variation of individuals in the sample population (Coladarci & Cobb, 2014).

To evaluate whether the three-way ANOVA was an appropriate statistical test for the purpose of this study, the following three assumptions were considered: the data must contain one continuous dependent variable; the data must contain three independent variables each consisting of two or more categorical groups; there must be independence of observations among the variables. Each of these assumptions was confirmed, thus validating the selection of the three-way ANOVA as an appropriate statistical test.

The research contained in this study was designed to produce findings about the influence of technology-assisted, independent mathematics practice that can be generalized to a broad population (Brannen, 2017).

Sample

A convenience, nonrandom sampling method was employed to form the sample population given the accessibility of the participating teacher and her students (Creswell, 2005). A 7th grade mathematics teacher at a middle school in Lafayette, Indiana agreed to participate in the study and assisted in facilitating both the treatment (experiment) and control (baseline) with her students during the fall semester of the 2018-2019 academic year.
The participating middle school, located in Lafayette, Indiana, is one of six middle schools in the Tippecanoe School Corporation, a comprehensive K-12 public school corporation encompassing 437 square miles of Tippecanoe Count, Indiana. The school corporation operates two high schools (grades 9-12), six middle schools (grades 6-8), and 11 elementary schools (grades K-5) serving 13,600 students and their families in the Greater Lafayette area. Founded in 1962 by the consolidation of the county’s eight township school districts, the Tippecanoe School Corporation contains a mix of rural, suburban, and industrial areas and is located in close proximity to Purdue University.

Serving approximately 700 students in grades 6-8, the middle school offers courses in Language Arts, Social Studies, Math, Science, Art, Music, Band, Choir, Technology Education, Family and Consumer Sciences, Health, and Physical Education. The student body is 63% White, 23% Hispanic, 8% Black, 5% Multiracial, and 1% Asian, with 43% of the students qualifying for free or reduced lunch. Students classified as Special Education with Individualized Education Plans (IEPs) comprise 21% of the student body.

The sample for the study consisted of 97 students aged 12 to 13 who were enrolled in the participating teacher’s 7th grade mathematics class during the fall semester of the 2018-2019 academic year. The sample was 57% White, 30% Hispanic, 3% Black, 8% Multiracial, and 1% Asian, with 37% of the students qualifying for free or reduced lunch. Students classified as Special Education with IEPs comprised 7% of the sample. The participating teacher was in her fifth year of teaching during the 2018-2019 academic year and her third year of teaching 7th grade mathematics at the middle school level. She graduated from Ball State University in May of 2014 with a Bachelor of Science degree in Elementary Education with an endorsement in
Secondary Mathematics. The participating teacher is currently pursuing her Master of Arts degree in Mathematics, also from Ball State University.

The participating teacher led six sections of 7th grade mathematics during the fall semester of the 2018-2019 academic year, with an average class size of 24 students. The teacher met with each section on a daily basis for a 45-minute class period. For the purpose of the study, three of the sections received the treatment while the other three sections did not. For students in the treatment group, exposure to the treatment did not begin until administration of the fall NWEA MAP mathematics assessment had concluded.

Students in both experimental groups received the same curriculum throughout the duration of the study, which was aligned to the Indiana Academic Standards. Classroom instruction and assessment were delivered consistently across all of the teacher’s sections, which included a balance of publisher-created and teacher-created curricular materials. Students in the treatment group had access to a school-issued laptop computer and the IXL program both at school and at home. Students in the control group also had access to a school-issued laptop but did not have access to the IXL program during the study.

Membership in the sample required students to be enrolled in the participating teacher’s mathematics classes for the duration of the study. Participation in the NWEA MAP mathematics assessment during the fall (pretest) and winter (posttest) administration windows was also a requirement. A demographic analysis of the sample is provided in chapter four.

**Population**

The population to which this study has attempted to generalize its findings is comprised of students between the ages of 12 and 13 who possess similar academic and demographic characteristics as the sample, who are enrolled in the 7th grade in a traditional middle school
setting. The students in the sample are demographically comparable to other middle school students in the state of Indiana, which allowed for the findings to be generalized to broad population (Norwood, 2010). Table 1 provides a demographic comparison for the sample and the population of 7th grade students in the state of Indiana for the 2018-2019 school year.

Table 1
Sample to Population Demographic Comparison

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sample Percentage</th>
<th>7th Grade Students in Indiana Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender – Female</td>
<td>51.7</td>
<td>48.4</td>
</tr>
<tr>
<td>Gender – Male</td>
<td>48.4</td>
<td>51.6</td>
</tr>
<tr>
<td>Ethnicity - Asian</td>
<td>1.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Ethnicity – Black</td>
<td>3.2</td>
<td>12.3</td>
</tr>
<tr>
<td>Ethnicity – Hispanic or Latino</td>
<td>29.7</td>
<td>12.6</td>
</tr>
<tr>
<td>Ethnicity – Multiracial</td>
<td>8.2</td>
<td>4.9</td>
</tr>
<tr>
<td>Ethnicity - White</td>
<td>56</td>
<td>67.5</td>
</tr>
<tr>
<td>Lunch Status – Free or Reduced</td>
<td>37.8</td>
<td>48.3</td>
</tr>
<tr>
<td>Lunch Status – Paid</td>
<td>62.3</td>
<td>51.7</td>
</tr>
</tbody>
</table>

Instrumentation

The instrumentation for this study included the usage of a technology-assisted, independent mathematics practice program (IXL) by the students in the treatment group and the measurement of mathematics proficiency through the NWEA MAP mathematics assessment for students in the sample.

Students assigned to the treatment group followed a prescribed weekly IXL usage plan throughout the duration of the study. Following administration of the fall NWEA MAP
mathematics assessment, students spent approximately five to 10 minutes answering questions in the Continuous Diagnostic area of IXL on the first day of each school week. Students were then given 10 minutes at the end of mathematics class each subsequent week day to practice mathematics skills in the IXL program. By the end of the week, students were expected to have completed approximately 50 minutes of independent skill practice. Students were only permitted to practice skills assigned to them by the IXL program based on their responses to the diagnostic questions at the beginning of the week. The participating teacher and I facilitated the administration of the usage plan and monitored student activity throughout the duration of the study. I generated reports from the IXL program on a weekly basis and provided them to the participating teacher to assist with oversight and administration. The participating teacher held students responsible for appropriate usage to ensure the usage plan was administered with fidelity.

Students assigned to the control group did not have access to the IXL program during the study and did not participate in any form of technology-assisted, independent mathematics skill practice. Classroom instruction and assessment were delivered consistently to students in the treatment and control groups. While students in the treatment group were provided five to 10 minutes at the end of each class period to independently practice mathematics skills using IXL, students in the control group were given five to 10 minutes of unstructured time at the end of each class period to start their homework assignment for the day. If students did not have homework to complete during this time, they were permitted “free time” wherein they could engage in independent reading, listen to music, or complete other tasks so long as they did not disrupt other students in the class.
**IXL.** IXL is an educational technology company that offers adaptive learning activities (IXL - Our Story, 2017). IXL’s learning activities provide opportunities for independent, isolated skill practice. As students practice skills, an IXL SmartScore is calculated. The SmartScore is based on IXL’s proprietary algorithm and is the best possible measure of how well a student understands a skill. When a student starts practicing a skill, the SmartScore starts at 0. As he or she answers questions correctly, the SmartScore increases. If a question is answered incorrectly, the score decreases. When a problem or question is answered correctly, the subsequent problem or question addresses the same skill, but at an increased level of difficulty. Conversely, when a problem or question is answered incorrectly, the subsequent problem or question addresses the same skill level, but at a decreased level of difficulty (IXL – How does the SmartScore work?, 2019).

Students in the treatment group used the Continuous Diagnostic feature in IXL at the beginning of each week. By answering a series of diagnostic questions, mathematics skills were assigned to each student for independent practice based at their level of mathematics proficiency. The skill practice students undertook during the remainder of the week was limited to the skills that had been assigned by the program’s Continuous Diagnostic feature, thus providing an individualized, practice experience. As students responded to diagnostic questions and practiced their recommended mathematics skills, their instructional level for each mathematics domain (Number & Operations; Algebra & Algebraic Thinking; Fractions; Geometry; Measurement; and Data, Statistics, & Probability) changed and new, additional skills were recommended. Figure 3 shows an example of the student view of the Continuous Diagnostic feature in IXL (IXL, 2017).
When a problem or question was answered incorrectly, an explanation was provided to students to describe why the response was incorrect. Although a brief explanation was provided after each question, the feedback was concise and should not be confused with more robust TMI solutions that offer direct instruction through self-paced tutorials. The intent of IXL is to provide independent practice opportunities through algorithmically generated questions, real-time analytical reports, and dynamic scoring to encourage student mastery (IXL, 2017). When engaged in practice, a time elapsed counter tracked the amount of time a student spent working on a given skill. If a student navigated away from the practice screen view a reward or search for a new skill, the timer did not record that as practice time. When inactivity was detected during skill practice, the timer paused and resumed only when the student began practicing again. Once

**Figure 3**: Student view of the IXL Continuous Diagnostic feature.
a student began accumulating practice time in IXL, they were presented with digital awards within the program, which could be earned for mastering skills, for spending time practicing, and for responding to a certain number of questions.

**NWEA.** As many K-12 schools have acquired greater access to technology, they have turned to computerized adaptive tests (CAT) to obtain a precise measure of the instructional level of each student (Brown et al., 2008). The NWEA MAP mathematics assessment is an example of this trend.

Like most computerized adaptive tests, the NWEA MAP tests use a unidimensional item response theory (RIT) model known as the Rasch Unit Scale, which is based on the premise that correlations among responses to test questions can be explained by a single underlying trait (Wang et al., 2013). The Rasch Unit Scale used by NWEA to represent student performance was conceived by Danish mathematician, George Rasch (NWEA, 2017). The Rasch model is used extensively in assessment in education, particularly for skill attainment and cognitive assessments.

The NWEA MAP mathematics test has proven to be an accurate method for measuring both the proficiency level and academic growth rate of individual students (Wang et al., 2013). The MAP mathematics test consists of seven domains: Number/Numeration Systems, Operations and Computation, Equations and Numerals, Geometry, Measurement, Problem-Solving, Statistics/Probability, and Applications. Test items are drawn from a bank of 15,000 that have been field tested, screened for bias and sensitivity issues, statistical qualities, and are calibrated for difficulty using Rasch modeling. On a periodic basis, NWEA conducts both reliability and validity studies to assess the qualities of the MAP tests (Brown et al., 2008).
Once a student completes the MAP test a scale (RIT) score is generated for each domain. The RIT scales are stable, equal interval scales that use individual item difficulty values to measure student achievement independent of grade level. An advantage to the RIT score is that it has the same meaning regardless of the grade or age of the student (NWEA, 2017). The RIT scores produced by the MAP tests measure a student’s level of achievement in a subject.

**Data Sources Collection Procedures**

Data were collected from both the IXL program and the NWEA MAP mathematics assessment for the purpose of this study. Demographic data for the students in the sample were collected from the participating school district’s student information system. All personally identifiable information was stricken from each data source prior to analysis.

Student rosters from the participating teacher’s mathematics classes were exported from the school district’s student information system. The export file contained the following fields: Internal student ID number (used to associate data), class section (to identify experimental group membership), gender (female, male), and lunch program status (free or reduced lunch, paid lunch).

Following the administration of the winter NWEA MAP mathematics assessment, an export was generated from the school district’s instance of the testing software. The export file contained the following fields for students in the sample: Internal student ID number (used to associate data), fall and winter mathematics RIT score. These fields were combined with the demographic data exported from the student information system to create a master data file that was used for the study’s analysis.
Data Analysis

The analysis of data sought to determine if a significant difference existed in the mathematics proficiency growth of students who independently practiced individualized mathematics skills using the IXL program for a period of 12 weeks (treatment) compared to students who did not use the IXL program during this period (control) while also testing the interaction effect of moderating categorical variables. IBM SPSS Statistics Version 25 was used to conduct a three-way ANOVA to test the interaction effect between experimental group membership, student gender, and student lunch program status in relation to mathematics proficiency growth.

To begin the analysis, I generated descriptive statistics for students in the sample to better understand the gender and lunch program status composition. To evaluate whether a three-way ANOVA was an appropriate statistical test for this study, the following assumptions were considered: there should be no significant outliers in any cell of the design; the dependent variable should be approximately normally distributed for each cell of the design; the variance of the dependent variable should be equal in each cell of the design (Brannen, 2017). According to Salkind (2010), an outlier is an observation in a set of data that is inconsistent with the majority of the data and is typically labeled an outlier if it is substantially higher or lower than most of the observations.

Next, I created boxplots to assess the presence of outliers in the data. A single outlier was identified and left in place. The outlier and its inclusion in the statistical testing is discussed further in chapter four. I then used the Shapiro-Wilk test for normality to evaluate the distribution of the dependent variable. The results of the test determined that mathematics
proficiency growth rates were normally distributed for each cell of the design (variable combination) except for one (female students with paid lunch status in the control group).

Once the appropriateness of using a three-way ANOVA was affirmed, I carried out the steps to conduct the test. Additionally, I created a profile plot to illustrate the three-way interaction effect among the variables in the study. Levene’s test for homogeneity of variances was then administered to evaluate the variances of the dependent variable across each independent variable combination. The results of the test determined there was homogeneity of variances for mathematics proficiency growth in each cell of the design. The results of the three-way ANOVA showed no statistically significant three-way interaction between experimental group membership, gender, and lunch program status in relation to mathematics proficiency growth.

Since a significant three-way interaction was not identified, each possible two-way interaction was assessed. A statistically significant two-way interaction between students’ gender and their lunch program status was identified. To further examine this interaction, the two variables were isolated and the simple main effects for lunch program status were tested. The simple main effects of lunch program status on mathematics proficiency growth for female students was determined to be statistically significant. Pairwise comparisons were then made for females using a Bonferroni adjustment. The difference in mathematics proficiency growth for female students with the lunch program status of free or reduced compared to female students with the lunch program status of paid was statistically significant.

Leveraging these methods offered a thorough, appropriate analysis of the variables in this study. As a result, a better understanding of the factors impacting mathematics proficiency growth for students in the sample was achieved. This information will serve to assist K-12
educational leaders in their adoption and implementation of the IXL program and offers an example of how the effectiveness of curricular resources can be assessed.

**Limitations of Study**

The size of the sample and the grade level of the students in the sample were limitations of the study. The sample was limited to 97 students enrolled in 7th grade. The small sample size in comparison to the overall population may limit the generalization of the study’s findings. Since the sample population consisted of only students enrolled in 7th grade, the findings may not be generalizable to students in other grade levels.

The study was also limited by the existence of confounding variables in the sample. Confounding occurs when two variables systematically covary, providing an explanation other than the independent variable for changes in the dependent variable (Salkind, 2010). The dependent variable in this study (mathematics proficiency growth rate) may have been affected by these uncontrolled variables. Potential confounding variables included unidentified learning disabilities, academic effort and desire to learn, external influences such as tutors, performance on prior mathematics proficiency tests, and exposure to other mathematics skill building activities outside of the experiment.

Although the study sought to provide a comparable educational experience for students in the treatment and control groups, the difference in how each group spent the last five to 10 minutes of their daily mathematics class period was also identified as an uncontrolled, confounding variable.

Another limitation of the study was its duration. The study lasted a total of 12 weeks, with students in the treatment group using the IXL program to independently practice individualized math skills for an average of 10 hours between the fall and winter NWEA MAP
mathematics assessments. It is possible the influence of the treatment could be different if the study were extended to a longer period.

Summary

This chapter described the design of the methods that were used to analyze the influence of technology-enhanced, independent mathematics practice on mathematics proficiency growth. The purpose of the study, including the independent and dependent variables, research questions, and hypotheses were also discussed. The overarching research design was shared in detail, including the rationale for the use of a quantitative analysis and the methods used to analyze and present the results. The sample population, instrumentation, and the design of the experiment were reviewed, along with the limitations of the study. In the next chapter, findings and analyses from the statistical tests used in this study are presented.
Chapter 4 – Presentation and Analysis of Data

This chapter begins by reviewing the purpose of the study. Descriptive statistics for the sample population are then provided. Findings from the assessment of outliers and variable distribution testing are detailed and the results from the three-way ANOVA are discussed. Lastly, a general summary of the statistical testing results is shared.

**Purpose of Study**

The purpose of this study was to determine if a significant difference existed in the mathematics proficiency growth of students who independently practiced individualized mathematics skills using the IXL program for a period of 12 weeks (treatment) compared to students who did not use the IXL program during this period (control). The independent, focal variable in this study was usage of the IXL program to independently practice individualized mathematics skills over the course of 12 weeks in the fall semester of the 2018-2019 academic year. This variable was applied to the treatment group of 51 7th grade students and was monitored by the students’ mathematics teacher during the study. Another group of 46 7th grade students, under the supervision of the same mathematics teacher, was assigned to the control group and did not use the IXL program during the study. The gender (male, female) and lunch program status (free or reduced lunch, paid lunch) of the students in the sample were also factored into the analysis as independent, moderator variables.

The dependent variable in this study was pretest to posttest mathematics proficiency growth for students in the sample. The data required to calculate the mathematics proficiency growth were generated through the fall and winter administration of the NWEA MAP mathematics assessment. The growth between tests was calculated by comparing the difference
between students’ mathematics RIT scores from the fall and winter administrations of the assessment.

**Descriptive Statistics**

To establish a better understanding of the variables in the study in relation to the students in the sample, I generated descriptive statistics in SPSS. Student gender and lunch program status were used as moderating independent variables in the study. Of the 97 students in the sample, 51.7% were female and 49.9% were male. The treatment group was 49% female and 51% male, while the control group was 54.3% female and 45.7% male. Students were categorized as having either free or reduced lunch status or paid lunch status. In the treatment group, 25.5% had the status of free or reduced lunch, while 74.5% of the students had the status of paid lunch. In the control group, 50% of the students had the status of free or reduced lunch, while 50% had the status of paid lunch.

Students in the sample had minimal variation of academic classification, with only three special education students in the treatment group and four special education students in the control group. Due to the lack of variation in academic classification it was not used as a moderating variable in the statistical testing.

Table 2

*Demographic Composition of Sample*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Control Group Percentage</th>
<th>Treatment Group Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender – Female</td>
<td>54.3</td>
<td>49</td>
</tr>
<tr>
<td>Gender – Male</td>
<td>45.7</td>
<td>51</td>
</tr>
<tr>
<td>Lunch Status – Free or Reduced</td>
<td>50</td>
<td>25.5</td>
</tr>
<tr>
<td>Lunch Status – Paid</td>
<td>50</td>
<td>74.5</td>
</tr>
</tbody>
</table>
To begin evaluating the mathematics proficiency growth of students in the sample, I compared their performance on the fall and winter NWEA MAP assessments. The average fall RIT score for students in the treatment group was 232.04, while the average score for students in the control group was 221.89. The average winter RIT score for students in the treatment group was 237.37, while the average score for students in the control group was 225.57. The average fall to winter growth for students in the treatment group was 5.33. The average fall to winter growth rate for students in the control group was 3.67. A summary of NWEA MAP mathematics assessment RIT scores for the sample is shown in table 3.

Table 3
Composition of Fall and Winter Mathematics RIT Scores

<table>
<thead>
<tr>
<th></th>
<th>Average Fall RIT Score</th>
<th>Average Winter RIT Score</th>
<th>Average Fall to Winter RIT Growth</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Group</td>
<td>232.04</td>
<td>237.37</td>
<td>5.33</td>
<td>4.84</td>
</tr>
<tr>
<td>Control Group</td>
<td>221.89</td>
<td>225.57</td>
<td>3.67</td>
<td>4.80</td>
</tr>
</tbody>
</table>

Identification of Outliers

To determine whether the data contained outliers, I generated boxplots in SPSS for each cell of the design. One outlier was assessed greater than 1.5 box lengths (fall to winter mathematics proficiency growth of 17 RIT units) for the design cell containing male students with the lunch program status of paid in the treatment group. After verifying the outlier was the result of a genuinely unusual value and not the result of a data entry or measurement error, I consulted the participating teacher to provide context. The teacher shared that while the student had a challenging start to the school year, he had shown significant improvement over the past 12 weeks. In her view, while the student’s fall mathematics proficiency score may have been
slightly lower than anticipated, his growth over the past few months was valid. Since there was no indication of subject or experimental error and given the teacher’s feedback and the relatively small size of the sample, I made the decision to leave the outlier in place. Although ANOVA is fairly robust against outliers (Brannen, 2017), inclusion of the outlier increased the risk for obtaining values that were not accurate representations of the population (Salkind, 2010). To address this concern, statistical testing was conducted both with the outlier and without the outlier in order to compare values and evaluate the findings. Figure 4 shows the boxplot chart used to identify the outlier in the design cell containing male students with the lunch program status of paid in the treatment group.

Figure 4: Boxplot chart for the design cell containing male students with the lunch program status of paid in the treatment group showing the single outlier.
Distribution of Dependent Variable

Since the three-way ANOVA assumes the data are normally distributed in each cell of the design, I used the Shapiro-Wilk test of normality to assess the distribution of the data in the study. Fall to winter mathematics proficiency growth rates were normally distributed \( (p > .05) \) except for one design cell (female students with paid lunch program status in the control group, \( p = .02 \)). Because the three-way ANOVA is fairly robust to deviations from normality, I decided to forego any intervention to address the violation of normality identified in this analysis.

Three-Way Interaction (ANOVA)

A three-way ANOVA was conducted to determine the effects of experimental group membership, gender, and lunch program status on fall to winter mathematics proficiency growth for students in the sample. I first generated a profile plot, shown in Figure 5, to illustrate the three-way interaction effect between the three independent variables in relation to the dependent variable. Visual inspection of the profile plot showed the highest level of fall to winter growth was exhibited by female students with the lunch program status of free or reduced who were members of the treatment group, followed by female students with the lunch program status of paid who were members of the treatment group.
Next, I administered Levene’s test for equality of variances to assess whether the variances in fall to winter mathematics proficiency growth rates were equal in all design cells. The results of the test showed there was homogeneity of variances for fall to winter mathematics proficiency growth rates for all combinations of experimental group membership, gender, and lunch program status, \( p = .59 \).

Results of the three-way ANOVA showed no statistically significant three-way interaction between experimental group membership, gender, and lunch program status in relation to mathematics proficiency growth, \( F(1, 89) = .60, p = .44 \). The complete results from the statistical test are shown in Table 4.
Table 4  
*Tests of Between-Subjects Effects*

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>248.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7</td>
<td>40.68</td>
<td>1.82</td>
<td>.09</td>
</tr>
<tr>
<td>Intercept</td>
<td>1880.30</td>
<td>1</td>
<td>1880.30</td>
<td>84.21</td>
<td>.00</td>
</tr>
<tr>
<td>Group</td>
<td>84.85</td>
<td>1</td>
<td>84.85</td>
<td>3.80</td>
<td>.054</td>
</tr>
<tr>
<td>Gender</td>
<td>70.24</td>
<td>1</td>
<td>70.24</td>
<td>3.15</td>
<td>.08</td>
</tr>
<tr>
<td>Lunch Status</td>
<td>15.21</td>
<td>1</td>
<td>15.21</td>
<td>.68</td>
<td>.41</td>
</tr>
<tr>
<td>Group * Gender</td>
<td>83.55</td>
<td>1</td>
<td>83.55</td>
<td>3.74</td>
<td>.06</td>
</tr>
<tr>
<td>Group * Lunch Status</td>
<td>2.59</td>
<td>1</td>
<td>2.59</td>
<td>.12</td>
<td>.73</td>
</tr>
<tr>
<td>Gender * Lunch Status</td>
<td>158.71</td>
<td>1</td>
<td>158.71</td>
<td>7.11</td>
<td>.01</td>
</tr>
<tr>
<td>Group * Gender * Lunch Status</td>
<td>13.40</td>
<td>1</td>
<td>13.40</td>
<td>.60</td>
<td>.44</td>
</tr>
<tr>
<td>Error</td>
<td>1987.29</td>
<td>89</td>
<td>22.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4277.00</td>
<td>97</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>2272.04</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.  a. R Squared = .13 (Adjusted R Squared = .06)*

Null Hypothesis One (H<sub>0</sub>1) was formulated as follows: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group. Because the results from the three-way ANOVA showed experimental group membership was not significant in relation to mathematics proficiency growth, $F(1,89) = 3.80, p = .054$, $H_01$ was not rejected.

Null Hypothesis Two (H<sub>0</sub>2) was formulated as follows: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared
to students in the control group students when considering their gender. Because results from the three-way ANOVA showed no significant interaction effect between group membership and gender in relation to mathematics proficiency growth, $F(1,89) = 3.74, p = .06$, $H_02$ was not rejected.

Null Hypothesis Three ($H_03$) was formulated as follows: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group students when considering their lunch program status. Results from the three-way ANOVA showed no significant interaction effect between group membership and lunch program status in relation to mathematics proficiency growth, $F(1,89) = .12, p = .73$, and as a result, $H_03$ was not rejected.

Null Hypothesis Four ($H_04$) was formulated as follows: There is no significant interaction effect among the variables of experimental group membership, gender, lunch program status, and mathematics proficiency growth. A significant two-way interaction was identified between students’ gender and lunch program status in relation to mathematics proficiency growth, $F(1,89) = 7.11, p = .01$), which resulted in the rejection of $H_04$.

**Simple Main Effects**

To further analyze the significant two-way interaction between students’ gender and lunch program status, the two variables were isolated so I could test the simple main effects for lunch program status. The simple main effects of lunch program status on fall to winter mathematics proficiency growth rates was significant for female students, $F(1, 89) = 5.49, p = .02$, but not for males, $F(1,89) = 1.9, p = .17$. All pairwise comparisons were made for females using a Bonferroni adjustment, shown below in Table 5. Mean fall to winter growth was 7.80 (SE = 1.40) for female students with the lunch program status of free or reduced and 4.03 (SE
difference of 3.71, 98% CI [.57, 6.97], \( p = .02 \).

Table 5  
Pairwise Comparisons

<table>
<thead>
<tr>
<th>Lunch Status</th>
<th>(I) Gender</th>
<th>(J) Gender</th>
<th>Mean Difference ((I-J))</th>
<th>Std. Error</th>
<th>Sig. (^b)</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>F/R</td>
<td>F</td>
<td>M</td>
<td>4.8*</td>
<td>1.73</td>
<td>.007</td>
<td>1.35</td>
<td>8.24</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>-4.8*</td>
<td>1.73</td>
<td>.007</td>
<td>-8.24</td>
<td>-1.35</td>
</tr>
<tr>
<td>Paid</td>
<td>F</td>
<td>M</td>
<td>-.96</td>
<td>1.29</td>
<td>.46</td>
<td>-3.53</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>.96</td>
<td>1.29</td>
<td>.46</td>
<td>-1.6</td>
<td>3.53</td>
</tr>
</tbody>
</table>

*Based on estimated marginal means

*The mean difference is significant at the .05 level

b. Adjustment for multiple comparisons: Bonferroni

Summary

A three-way ANOVA was conducted to assess the effects of experimental group membership, gender, and lunch program status on fall to winter mathematics proficiency growth for students in the sample. There was one outlier assessed as a value greater than 1.5 box lengths from the edge of the box which was not changed. Proficiency growth was normally distributed \((p > .05)\) except for one group (female students with paid lunch program status in the control group, \( p = .02 \)), as assessed by Shapiro-Wilk’s test of normality. There was homogeneity of variances, as assessed by Levene’s test for equality of variances, \( p = .99 \). There was no significant three-way interaction between experimental group membership, lunch program status, and gender, \( F(1, 89) = .60, p = .44 \). Additionally, there was no significant two-way interaction
between experimental group membership and gender \((F(1, 89) = 3.74, p = .06)\) or between experimental group membership and lunch program status \((F(1, 89) = .12, p = .73)\). As a result, \(H_01, H_02,\) and \(H_03\) were not rejected.

There was a significant interaction between students’ gender and their lunch program status, \(F(1, 89) = 7.11, p = .01\). As a result, \(H_04\) was rejected. The simple main effects of lunch program status on fall to winter mathematics proficiency growth was significant for female students, \(F(1, 89) = 5.49, p = .02\), but not for males, \(F(1, 89) = 1.91, p = .17\). All pairwise comparisons were made for females using a Bonferroni adjustment. Mean fall to winter mathematics proficiency growth was 7.80 (SE 1.40) for female students with the lunch program status of free or reduced and 4.03 (SE .80) for female students with the lunch program status of paid, a statistically significant difference of 3.71, 98% CI [.57, 6.97], \(p = .02\).

This chapter began by reviewing the purpose of the study and descriptive statistics for the sample population. The findings from the outlier and variable distribution testing were detailed and a discussion surrounding the existence of a single outlier in the data was shared. A thorough description of the ANOVA testing was provided and the results were presented. Hypotheses testing was conducted and the decision to reject or not reject each null hypothesis was discussed. The basis for conducting additional testing to evaluate the simple main effects of gender and lunch program status was outlined and results from this testing were shared. In the next chapter, an extensive review of the hypotheses testing is offered along with other findings from the study. Recommendations for future research are shared and the study’s implications for educational leadership are discussed.
Chapter 5 – Conclusions and Implications for Future Research

This chapter begins by reviewing the purpose of the study and the problem it sought to investigate. The study’s research questions are shared, followed by a description of the research methods used. Results of hypotheses testing are discussed, along with other findings and recommendations for future research. The chapter concludes with implications for educational leaders and a general summation of the study.

The purpose of this study was to determine if a significant difference existed in the mathematics proficiency growth of students who independently practiced individualized mathematics skills using the IXL program for a period of 12 weeks during the fall semester of the 2018-2019 school year compared to students who did not use the IXL program during this period. The independent, focal variable in this study was usage of the IXL program to independently practice individualized mathematics skills. The gender and lunch program status of the students in the sample were factored into the analysis as independent, moderator variables and their interaction effect on the focal variable was assessed.

The problem this study sought to address was whether student usage of the IXL program to independently practice individualized mathematics skills led to increases in mathematics proficiency growth. This problem, while examined in isolation for the purpose of this study, stems from another, more complex problem: declining mathematics proficiency rates by students in the United States (OECD, 2017; U.S. Department of Education, 2017) and the expectation of educational leaders to improve student outcomes (Robinson, 2015; Wagner & Dintersmith, 2015; Zhao, 2015). Given this expectation, many educational leaders have turned to the IXL program as a supplemental curricular resource.
Two questions guided my research for this study, which were developed based on the problem the study sought to address and research in areas related to mathematics proficiency and learning theory.

1. What influence does technology-assisted, independent mathematics practice that is individualized to each student’s level of proficiency have on mathematics proficiency growth as measured by the NWEA MAP assessment in a sample of 7th grade students?

2. What effect do the moderator variables of gender and lunch program status have on the influence of technology-assisted, independent mathematics practice that is individualized to each student’s level of proficiency and mathematics proficiency growth as measured by the NWEA MAP assessment in a sample of 7th grade students?

A convenience, nonrandom sampling method was employed to form the sample population given the accessibility of the participating teacher and her students (Creswell, 2005). A 7th grade mathematics teacher at a middle school in Lafayette, Indiana agreed to participate in the study and assisted in facilitating both the treatment and control with her students during the fall semester of the 2018-2019 academic year.

Students assigned to the treatment group followed a prescribed weekly IXL usage plan throughout the duration of the study. Following administration of the fall NWEA MAP mathematics assessment, students spent approximately five to 10 minutes answering questions in the Continuous Diagnostic area of IXL on the first day of each school week. Students were then given 10 minutes at the end of mathematics class each subsequent week day to practice mathematics skills in the IXL program. By the end of the week, students were expected to have completed approximately 50 minutes of independent skill practice. Students were only permitted to practice skills assigned to them by the IXL program based on their responses to the diagnostic
questions at the beginning of the week. The participating teacher and I facilitated the administration of the usage plan and monitored student activity throughout the duration of the study. I generated reports from the IXL program on a weekly basis and provided them to the participating teacher to assist with oversight and administration. The participating teacher held students responsible for appropriate usage to ensure the usage plan was administered with fidelity.

Students assigned to the control group did not have access to the IXL program during the study and did not participate in any form of technology-assisted, independent mathematics skill practice. Classroom instruction and assessment were delivered consistently to students in the treatment and control groups. While students in the treatment group were provided five to 10 minutes at the end of each class period to independently practice mathematics skills using IXL, students in the control group were given five to 10 minutes of unstructured time at the end of each class period to start their homework assignment for the day. If students did not have homework to complete during this time, they were permitted “free time” wherein they could engage in independent reading, listen to music, or complete other tasks so long as they did not disrupt other students in the class.

A quantitative, quasi-experimental research design was used to determine if there was a statistically significant difference in the mathematics proficiency growth of students who independently practiced individualized mathematics skills using the IXL program compared to students who did not. The design used in this study leveraged a nonequivalent control-group with nonrandom treatment and control group assignment of participants (Creswell, 2005). Following the pretest and posttest, demographic and assessment data were used to conduct a three-way ANOVA with a 2 x 2 x 2 design. The analysis tested the interaction between variables
to determine whether the independent focal variable had a statistically significant effect on the dependent variable and whether the effect was influenced by the value of other independent moderator variables.

**Review of Hypothesis Testing**

A three-way ANOVA was used to test the null hypotheses and to examine the interaction effect between the independent variables and the dependent variable. Demographic data for students in the sample and their results from the fall and winter NWEA MAP mathematics assessments were input into SPSS to conduct the statistical testing for this study.

$H_0$: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group.

Testing results showed experimental group membership was not significant in relation to mathematics proficiency growth, $F(1,89) = 3.80, p = .054$, and as a result, the null hypothesis was not rejected. Although testing resulted in the null hypothesis not being rejected due to the significance value exceeding .05, it should be noted that group membership was close in proximity to the significance threshold ($p = .05$). This proximity, combined with the treatment group averaging a fall to winter RIT growth rate 1.66 units higher than the control group, indicates a potential positive interaction between membership in the treatment group and mathematics proficiency growth.

Research has identified the need to differentiate instruction to meet the diverse proficiency levels of the students in a typical classroom (Poncy et al., 2013). To improve learning outcomes and increase instructional efficiency, teachers require interventions that can be applied to students simultaneously yet differentiate instruction by providing the appropriate level of challenge for each student (Musti-Rao & Plati, 2015). Students assigned to the treatment
group in this study utilized the IXL program to engage in technology-assisted, individualized mathematics practice. Each student’s practice experience was unique based on their activity in the program’s Continuous Diagnostic area, with skill practice individualized to each student’s level of proficiency.

Statistical testing revealed that students’ membership in either experimental group was not significant in relation to their mathematics proficiency growth ($p = .054$). Although membership in the treatment group and exposure to technology-assisted, individualized mathematics practice was not found to be statistically significant, the borderline significance level of $p = .054$, coupled with the treatment group’s higher rate of proficiency growth from fall to winter compared to the control group, supports the findings of a previous study in which students who practiced mathematics for 15 minutes a day over a period of five weeks showed improved performance compared to their peers (Kucian et al., 2011). These positive findings reinforce the argument that math practice must be interactive, individualized, and provide students with a sustained positive experience of success (Stacy et al., 2017).

$H_0$: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group students when considering their gender.

Statistical testing revealed no significant interaction effect between group membership and gender in relation to mathematics proficiency growth, $F(1,89) = 3.74, p = .06$. As such, these results supported $H_0$ not being rejected. An outlier was present in this cell of the design and was discussed at length in chapter four. Since there was no indication of subject or experimental error and given the teacher’s feedback and the relatively small size of the sample, I made the decision to leave the outlier in place. Because of the close proximity to significance
shown with several of the variables, I also conducted the three-way ANOVA with the outlier excluded. When the outlier was excluded from the data, the significance of the interaction between gender and group membership changed from $p = .06$ to $p = .03$. The proximity of the interaction to significance when the outlier was included, coupled with the significance of the interaction when the outlier was excluded, indicates a potential positive two-way interaction between female gender and membership in the treatment group in relation to mathematics proficiency growth. Visual inspection of the profile plot shown in Figure 5 supports this finding, with the greatest fall to winter proficiency growth exhibited by female students in the treatment group, even when including the outlier.

$H_{03}$: There is no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group students when considering their lunch program status.

Analyzing the results of the three-way ANOVA showed no significant difference between the mathematics proficiency growth rates of students in the treatment group compared to students in the control group when considering their lunch program status. Statistical testing revealed no significant interaction effect between group membership and lunch program status in relation to mathematics proficiency growth, $F(1,89) = .12, p = .73$, and as a result, $H_{03}$ was not rejected. Excluding the outlier from the ANOVA testing resulted in the same determination ($p = .60$). Based on these results, it appears unlikely that lunch program status influenced the mathematics proficiency growth of students in the sample.

$H_{04}$: There is no significant interaction effect among the variables of experimental group membership, gender, lunch program status, and mathematics proficiency growth.
Although the results of the ANOVA testing did not reveal a significant three-way interaction effect between group membership, gender, and lunch program status, a significant two-way interaction between gender and lunch program status was shown. Due to the significance of this interaction, $F(1,89) = 7.11, p = .01$, $H_0$ was rejected. Additional testing was conducted to further investigate the interaction between gender and lunch program status. The simple main effects of lunch program status on fall to winter mathematics proficiency growth for female students was found to be significant, $F(1,89) = 5.49, p = .02$, but not for males, $F(1,89) = 1.91, p = .17$. Fall to winter mathematics proficiency growth was 7.80 (SE = 1.40) for female students with the lunch program status of free or reduced and 4.03 (SE = .80) for female students with the lunch program status of paid, a significant difference of 3.71, 98% CI [.57, 6.97], $p = .02$.

The results of this hypothesis test and the additional investigation of the positive interaction between gender, lunch program status, and mathematics proficiency growth showed that female students in the study with the lunch program status of free or reduced lunch had significant mathematics proficiency growth when controlling for other variables in the study. This finding, along with the results from the testing of $H_02$, appear to support the conclusion that female students in this study demonstrated significantly higher rates of mathematics proficiency growth compared to their male classmates when controlling for the other independent variables. This finding appears to be especially significant for female students with the lunch program status of free or reduced lunch and female students in the treatment group.

The finding that female students demonstrated higher rates of mathematics proficiency compared to their male counterparts in this study corresponds to other research that shows female students are now outperforming male students across multiple academic disciplines. In
their analysis of data from the most recent PISA examination, Stoet and Geary (2015) found that female students are outperforming male students in reading, mathematics, and science by the age of 15, regardless of political, social, or gender equality issues and policies found in their home country. Although the achievement rates of male and female students are comparable in the United States, recent data from the U.S. Department of Education show females comprise a growing majority of students enrolled in colleges and universities, outnumbering their male counterparts by approximately 2.2 million in the 2017 academic year (U.S. Department of Education, 2017).

Despite the interaction effect between membership in the treatment group and mathematics proficiency growth not being statistically significant ($p = .054$), the interaction was still relatively strong and close to the significance threshold. Students in the treatment group who independently practiced individualized mathematics skills using the IXL program had, on average, a higher rate of proficiency growth from fall to winter compared to students in the control group who did not use IXL. This finding supports the body of research that has found independent, individualized mathematics practice to positively impact the acquisition of mathematical skills (Louw et al., 2008; National Mathematics Advisory Panel, 2008).

**Other Findings**

Once the statistical testing was complete, I conferred with the participating teacher to share the results. Through informal discussion, she shared her opinion about the difference in the maturity levels of male and female students in her classes, with female students generally showing a higher level of overall maturity at this age. Moreover, she expressed concern that many of the male students in her classes appeared highly distracted when using their laptops. She went on to discuss the perceived obsession many of the male students in her classes have
with video games and gaming in general; it was a frequent occurrence to find male students seeking out video games when using their laptops or watching online videos about video games. Although subjective and based on anecdotal observations, the participating teacher hypothesized that the treatment may have been more influential for female students due to their ability to stay on task when practicing mathematics skills on their laptops.

When discussing the finding that female students appeared to demonstrate higher rates of mathematics proficiency growth than their male classmates regardless of experimental group membership and other variables, the participating teacher again shared the challenges she experiences in keeping her male students engaged and on task during mathematics class. In general, the participating teacher felt that female students at this grade level appeared to be more interested in and attentive to their academic pursuits compared to their male classmates. She hypothesized this could be due to the age of the students and differences in their maturity levels.

The feedback shared by the participating teacher regarding the behavioral differences she observed between male and female students in her classes aligns with previous research on the growing gender gap in academic achievement. In an analysis of high school GPA trends, researchers found a growing disparity between male and female students, with female students consistently earning a higher GPA compared to their male counterparts (Fortin et al., 2015). The study also identified a strong correlation between gender, motivation, and academic achievement among 8th grade students, with female students demonstrating higher levels of motivation and achievement and male students demonstrating lower levels of motivation and achievement (Fortin et al., 2015).
Recommendations for Future Research

Past research has shown a positive relationship between technology-based instructional resources and mathematics proficiency (Slavin & Lake, 2008). Instructional activities that offer individualized practice opportunities are considered important to the acquisition of knowledge and skills (Louw et al., 2008). While the body of research on technology-mediated instruction is extensive, this study sought to fill a gap in the literature through its investigation of the relationship between informal mathematics practice and mathematics proficiency (Stacy et al., 2017). The findings from this study have led to a series of recommendations for future research.

The results from the statistical testing in this study showed a near significant interaction effect between experimental group membership and mathematics proficiency growth, with membership in the treatment group having a positive influence on proficiency growth. Given the small sample size ($n = 97$), the age of the students in the sample (12-13 years old), and the duration of the study (12 weeks), subsequent research should attempt to replicate the experiment on a larger scale, with students from a wider age range, over a more extended period. While the results from this study could be generalized to a population similar in age and demographics to the students in the sample, conducting a similar experiment with a larger, more diverse sample that is longer in duration may yield results that could be generalized to a broader population.

The hypothesis testing for $H_02$ and $H_04$ revealed potential interaction effects between experimental group membership, gender, lunch program status, and mathematics proficiency growth. Hypothesis testing for $H_02$ showed a potential positive interaction between female gender, membership in the treatment group, and mathematics proficiency growth. Hypothesis testing for $H_04$ revealed female students in the study with the lunch program status of free or reduced lunch had significant mathematics proficiency growth when controlling for all other
variables. When taken together, results from these tests appear to indicate that female students in
the study demonstrated higher rates of mathematics proficiency growth compared to their male
classmates. Post-study conversations with the participating teacher regarding her observations
about academic engagement and gender in her classes appear related to these findings.

Future research on the influence of technology-assisted mathematics skill practice,
mathematics proficiency, and gender differences is warranted. While the results from this study
seem to support the conclusion that students responded differently to the treatment based on their
gender, there is also an indication that mathematics proficiency growth in general is influenced
by gender. Subsequent studies could seek to investigate a collection of variables known to
influence mathematics proficiency while controlling for student gender. A qualitative study that
seeks to understand the differences in maturity and learning motivators for middle school
students based on their gender would also be of value. There is a myriad of hypotheses as to the
cause of the growing achievement gap between male and female students. Further research on
the achievement gap as it relates to mathematics proficiency and technology-assisted
mathematics skill practice would be a worthy addition to the body of research.

**Implications for Educational Leaders**

The list of responsibilities for educational leaders is exhaustive. In recent years, the
expectation of educational leaders to help make resources available that improve student
outcomes has become more prominent (Robinson et al., 2008). Despite competing demands and
limited resources, it is critical for educational leaders to select resources that have proven to be
effective in increasing student learning (Slavin & Lake, 2008). This study and its findings offer
important implications for educational leaders.
The market for curricular materials and supplemental resources is very competitive. With the prevalence of open educational resources (OER) and free web-based options, traditional content publishers and software companies that develop educational products have grown increasingly aggressive in their sales tactics. From special promotions to promises of improved learning outcomes, educational leaders are frequently exposed to these practices during the resource selection process. While this study focused on the influence of one technology-based resource (IXL), its findings can help educational leaders develop a better understanding of how to evaluate the effectiveness of curricular resources in general.

A subjective approach is often taken when selecting curricular materials, with teacher preference usually playing a prominent role. In addition to teacher preference, word of mouth, experience with a publisher or company, and the cost of the materials also factoring into the selection process. The conceptual framework and research model developed for this study, along with its findings, should encourage educational leaders to take an evidence-based approach when evaluating and selecting curricular materials.

Educational leaders should be critical of research studies about the effectiveness of a product that are provided by the company selling the product. Frequently, these studies are funded by the company and can be biased in their findings. A valuable resource for educational leaders is the What Works Clearinghouse (https://ies.ed.gov/ncee/wwc/), a website made available by the Institute of Educational Sciences. The What Works Clearinghouse contains reviews of existing research on different programs, products, practices, and policies in education, with the goal of providing educators with the information they need to make evidence-based decisions (What Works Clearinghouse, 2019). The reviews available on the website focus on results from high-quality research studies and are intended to help educators become more
informed in their evaluation of educational resources. Because few educational leaders have the
time and resources to design a research study in preparation of selecting a new curricular
resource, the What Works Clearinghouse can play a critically important role in the selection
process.

Another implication for educational leaders reinforced by this study is the need to
understand the differences in the student population and to be cognizant that curricular resources
may not have the same effect on all students. In K-12 education, curricular resources are
frequently adopted and then delivered to all students in a consistent manner. As such, for the
purpose of this study, the IXL usage plan was prescribed consistently to all students in the
treatment group. The findings from this study showed that female students tended to benefit
most from using IXL, as they exhibited higher rates of mathematics proficiency growth
compared to their male classmates. While not examined in this study, the likelihood that
practitioners assign IXL usage consistently to both male and female students is high. This study
calls into question the effectiveness of this practice and urges educational leaders to monitor the
application of curricular resources in comparison to student proficiency data. Although a
curricular resource may positively influence academic proficiency for one subgroup of students,
its influence may not be as favorable with another.

**Summary**

This study investigated the influence of technology-assisted, independent mathematics
practice that was individualized to students’ proficiency levels on their mathematics proficiency
growth as measured by the NWEA MAP mathematics assessment. Over a 12-week period, 51
7th grade students used the IXL program to practice mathematics skills during their daily
mathematics class. A comparable group of 46 7th grade students did not practice mathematics
skills using IXL during this period. Using the fall and winter administrations of the NWEA MAP mathematics assessment as a pretest-posttest design, results from both assessments were analyzed in relation to the independent variables.

A three-way ANOVA was used to test the interaction effect between usage of the IXL program and mathematics proficiency growth, while also taking into account the moderator variables of student gender and lunch program status. The results showed that female students with the lunch program status of free or reduced lunch had significant mathematics proficiency growth when controlling for the other variables. In general, female students demonstrated higher rates of mathematics proficiency growth compared to their male classmates when controlling for the other variables. This finding was especially significant for female students with the lunch program status of free or reduced lunch and female students who independently practiced mathematics skills using IXL due to their membership in the treatment group.

In conclusion, the findings from this study showed a positive interaction between usage of the IXL program and mathematics proficiency growth for students in the treatment group. This interaction was particularly significant for female students. Future research on the influence of technology-assisted practice activities, mathematics proficiency, and gender differences is warranted. This study offers implications for educational leaders, such as the need to take an evidence-based approach when selecting curricular materials and the importance of understanding the influence of a curricular resource on each subgroup within a student population.
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