MATHCONCEPTZ: AN EXPERIMENTAL DESIGN TO IMPROVE MATH PERFORMANCE

BY

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ABSTRACT

Educational policymakers have been working to strengthen mathematics education by adopting rigorous mathematics standards that promote a conceptual understanding of math. Though this shift is nationwide, Black and Hispanic students in urban schools tend to be exposed to math instruction that emphasizes rote memorization and procedural knowledge of math. One reason attributed to the poor performance of students in math in urban schools is the lack of high quality instruction.

The purpose of this dissertation was to test the impact of an intelligent tutoring system, MathConceptz, that aims to improve student performance in Algebra. Using pre- and post-test results, this study sought to demonstrate whether MathConceptz builds students' conceptual understanding of Algebra topics, as well as provides a possible solution to the issue of poor teacher quality in urbans schools. The research questions that guided this study were: How do pre- and post-test results compare from the face-to-face instruction group and the blended learning (face-to-face and existing ITS) group? How do pre- and post-test results compare between the face-to-face instruction group and the MathConceptz group? How do pre- and post-test results compare between the blended learning (face-to-face and MathConceptz) group and the MathConceptz group?

An experimental research design was employed to test the impact of MathConceptz on student pre- and post-test results. A sample of 79, 8th and 9th grade students were administered a pre-test and received face-to-face instruction, MathConceptz instruction, or a combination of both, followed by a post-test. An ANOVA was conducted on the data collected to show the impact of

MathConceptz measured against several variables including teacher quality and student demographics.

Findings from this study showed a significant difference in test scores between the face-to-face instruction group and the blended instruction group. These findings suggest that using intelligent tutoring systems, such as MathConceptz, to supplement instruction may be a viable solution to the issue of instructional quality in urban areas, while also building students’ conceptual understanding of math.

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"My brain… it cannot process failure. It will not process failure. Because if I sit there and have to face myself and tell myself, 'You're a failure'… I think that's almost worse than death."

~ Kobe Bryant

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DEDICATION

This dissertation is dedicated to my loving husband and children.

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CHAPTER 1: STATEMENT OF THE PROBLEM

Introduction

Success in the labor market and economic prosperity in the United States (Riegel-Crumb & King, 2010) are linked to high performance in mathematics (Mongeau, 2013). High school graduates with advanced math qualifications have higher test scores, attain a higher education, and earn a higher income than graduates without these qualifications (Joensen & Nielson, 2009). In particular, Algebra I is seen as a foundational course that acts as a gatekeeper to the college preparatory pathway in secondary education. Educational policymakers have been working to strengthen STEM education (Diamond, 2007; Thomasian, 2011; Hossain & Robinson, 2012), particularly in mathematics (Covay, 2011). One such initiative is the adoption of rigorous mathematics standards and improved assessments through the Common Core Standards initiative (Thomasian, 2011). Based on the goals outlined in the National Council of Teachers of Mathematics (NCTM) (Jackson & Wilson, 2012), the Common Core standards call for a shift from traditional mathematics education, which has emphasized procedural knowledge and rote learning, to developing a conceptual understanding of mathematics for students to be mathematically proficient (Balka, Hull, & Miles, 2003; Diamond, 2007; Jackson & Wilson, 2012).

A conceptual understanding of mathematics means having the ability to recognize and understand the core underlying ideas of a concept, and to apply those ideas to new contexts (Burns, Walick, Simonson, Dominguez, Harelstad, Kindcaid, d`& Nelson, 2015). A conceptual understanding allows students to apply and adapt acquired mathematical ideas to new situations (Balka et al., 2003) and develop enduring understandings of mathematics (Jackson & Wilson, 2012). In a concept-based mathematics classroom, mathematical thinking involves understanding relations among multiple strategies, errors provide opportunities to reconceptualize a problem, and collaborative work involves reaching a consensus through mathematical argumentation (Kazemi & Stipek, 2001).

Unfortunately, urban high schools that mainly serve students from historically marginalized populations, typically low-income Black and Hispanic students (Lewis, 2007), are least likely to offer the type of mathematics instruction that allows students to meet the new standards and develop this conceptual understanding (Becker & Luthar, 2002). Instruction in urban high school districts tends to emphasize lower order rote skills and teacher-directed activities (Becker & Luthar, 2002), and the tendency is to expose these students to a more watered-down curriculum than their more affluent peers who are enrolled in more challenging classes (Crosnoe, Morrison, Burchinal, Pianta, Keating, Friedman, & Clarke-Stewart, 2010). Strutchens and Silver (2000) report that White and more affluent students typically have teachers who go beyond computational skills and emphasize reasoning skills and the use of calculators to solve unique math problems. Affluent White students tend to be exposed to conceptual and higher-order instruction that emphasizes reasoning and non-routine problem solving, technology, and mathematics instruction through simulations and applications (Oakes, 1985; Becker & Luther, 2002; Akiba, LeTendre, & Scribner, 2007; Flores, 2007; Darling-Hammond, 2000). Perhaps not surprisingly, in a national sample of Black children’s perceptions of mathematics, the majority of students reported that, “there is one way to solve a math problem” and “learning math is mostly memorizing facts” (Strutchens & Silver, 2000).

Factors Contributing to Differences in Instruction

The difference between the quality of instruction in high schools serving mainly disadvantaged students, compared to those serving advantaged students has played a significant role in the long-lasting achievement gap between Black and Hispanic, and White students (Akiba, 2007). Several interrelated factors have been found to contribute to these differences in instructional quality. These factors include teacher quality, school course offerings, and access to resources (Burris & Welner, 2005; Flores, 2007; Desimone & Long, 2010). Possibly the most important of these factors is teacher quality. Highly qualified teachers are those that are fully certified, possess a bachelor's degree, and demonstrate competence in subject matter knowledge and teaching as these factors have been identified as significantly associated with higher student achievement (Darling-Hammond, 2000; Darling-Hammond & Young, 2002; Akiba, 2007; Boyd, Lankford, Loeb, Rockoff, & Wyckoff, 2008).

Typically, however, low-income, low-achieving, minority students in urban areas are taught by the least skilled teachers (Lankford, Loeb, & Wyckoff, 2002; Borman & Kimball, 2005; Peske & Haycock, 2006; Flores, 2007). In fact, high-poverty and ethnic minority students are twice as likely as low-poverty and majority students to be assigned novice teachers new to the profession (Peske & Haycock, 2006; Akiba, 2007), teachers who are uncertified (Akiba, 2007) or out-of-field (Borman & Kimball, 2005), and teachers without a college major or minor – "a low-bar in terms of demonstrating content knowledge" (Peske & Haycock, 2006, p. 3). In distributing teacher quality inequitably the achievement gap widens (Peske & Haycock, 2006), making teacher quality and pedagogical expertise one of the most influential factors contributing to differences in the quality of instruction (Flores, 2007).

Online Learning/Intelligent Tutoring Systems

Concerns of equity and access to quality education have helped to spur the growth of online learning in K-12 education (Smith, Clark, Blomeyer, 2005), particularly in mathematics (Cascaval, Fogler, Abrams, Durham, 2007), as one possible solution to the problem of teacher quality. Online learning models have evolved to include intelligent tutoring systems (ITS'). In the purely online model, teaching occurs solely through the use of communications technology such as computers, e-mail, television, and videotape. These forms of communication allow students and instructors to be separated by geographic distance and time, while still potentially improving the quality of learning (Appana, 2008). ITS', however, are instructional software that emphasize active learning and customize instruction for individual students using artificial intelligence algorithms (Beal, Arroyo, Cohen, & Woolf, 2010; Pane et al., 2013). Because ITS' provide customized instruction, they are potentially a viable solution to the issue of teacher quality in disadvantaged communities. The assumption is that by allowing students to engage with a system that is able to diagnose and adapt to students' knowledge and skills, students' performance in mathematics will improve (Chien et al., 2008).

ITS' possess several key features that allow students to construct their own knowledge, which is necessary to improving mathematics outcomes. ITS' are designed based on a continuous assessment of students' Zone of Proximal Development (ZPD) and scaffolding within the ZPD. The ZPD is the distance between the problems a student can complete without assistance and problems that the student can solve with the assistance of a teacher or tutor (Stuyf, 2002; Beal et al., 2010). ITS' are based on the hypothesis that students learn most when solving problems that fall within their ZPD, alternating between problems that students can solve easily and those that are more challenging. With challenging problems, ITS' allow students to make errors and receive scaffolds in the form of hints. ITS' also pose questions and provide examples to guide students toward the solutions. Feedback is important in any effective learning environment, but more so in online learning where human tutors are not present, because it stimulates the learner's cognitive processes and prevents the re-occurrence of misconceptions (Azedo & Bernard, 1995). The ability of ITS' to scaffold instruction within students' ZPD results in individualized instruction that is responsive to students' learning needs (Beal et al., 2007). Lastly, ITS' create asynchronous environments, environments in which students learn at their own pace. In short, ITS' encourage the de-emphasis of procedural math and place more emphasis on math reasoning to prepare students for college and careers (Corbett, Koedinger, & Anderson, 1997). However, the emphasis placed on math reasoning fails to include an emphasis on teaching the actual concepts behind the math that students are learning, as evidenced by current ITS' focus on providing shortcuts to math procedures and student gains that are based in procedural knowledge (Yaraton, 2003; Phillips & Johnson, 2011).

Research on Intelligent Tutoring Systems in Mathematics

The research base suggests that ITS programs designed to support exploratory learning while improving students' basic computational skills have yielded significant student improvement in math (Melis & Siekmann, 2004; Razzaq, Feng, Nuzzo-Jones, Heffernan, Koedinger, Junker, Ritter, Knight, Mercado, Turner, Upalekar, Walonoski, Macasek, Aniszczyk, Choksey, Livak, & Rasmussen, 2005; Beal et al., 2010; Pane et al., 2013). Several studies have compared student performance on math pre- and post-tests as a result of ITS'. For example, the impact of ITS' such as the PUMP Algebra Tutor (PAT), Active Math, The Cognitive Tutor, The ASSISTment system, and AnimalWatch, on student performance has been tested in separate studies. PAT, the Cognitive Tutor, and Animal Watch focus on algebra while the ASSISTment system focuses on general mathematics topics (Koedinger, Anderson, Hadley, & Mark, 1997; Razzaq et al., 2005; Beal et al., 2010; Pane et al., 2013). In a study of PAT that utilized a problem solving environment that included tasks that described relationships among quantities and required students to generate an algebraic description of the relationships and graph the relationships, the results showed that students who worked through the PAT course scored 100% higher on their year-end assessments than students who took a traditional algebra course on reasoning and problem solving. (Koedinger et al., 1997). Similarly The Cognitive Tutor and The ASSISTment system, were tested on 18,700 and 1,000 high school students respectively, and resulted in increased end-of-year student test performance (Razzaq et al., 2005; Pane et al., 2013), The Cognitive Tutor showed a greater improvement in performance for lower achieving students (Pane et al., 2013). Results from the other ITS did not show a distinction between the performance of lower and higher achieving students. Though these types of studies test the impact of each ITS on student performance, there are no current studies that compare different ITS' and identify the ITS' that have the greater impact on student performance.

While studies generally suggest that ITS' improve student performance (Corbett et al., 1997; Razzaq et al., 2005; Beal et al., 2010; Clark & Whitestone, 2014) in mathematical processes, higher order thinking, and problem solving skills as measured by pre- and post-test scores, there are counterarguments that show there are some limitations to these programs. Critics argue that current studies only show results of using ITS' as a supplement to face-to-face instruction, as opposed to in lieu of face-to-face instruction (Clark & Whitestone, 2014). Second, all ITS' are not created equal.

While some ITS’ show positive impact, some show no impact or worse, depending on the type of software used (Beal et al., 2010). For example, the activities in the ITS’ reviewed in a study by Dynarski et al. (2007) were primarily drill and practice activities that lacked the multimedia and interactive components necessary for an effective ITS that improves student outcomes. In addition, while these systems test and correct students’ knowledge and provide instruction in the form of feedback when a student gets an incorrect answer, the feedback provided is often procedural and fails to uncover the concept behind a math topic. Though students are able to correct their responses, given the feedback, they do not necessarily improve their conceptual understanding of the math. Lastly, not all ITS’ are aligned to the Common-Core curriculum (Clarke & Whitestone, 2014), and as a result, are not aligned to the Common-Core exams therefore, these ITS’ may not be adequately exposing students to grade-level curriculum.

Purpose of the Study

Though there is the potential for ITS’ to address the issue of teacher quality by supplementing instruction, it seems that the research base is suggesting that some may fall short because no one has developed an ITS that aims to build conceptual knowledge of math nor has the use of an ITS alone as an instructional model been explored. The research base suggests that the use of ITS’ contributes to improvement in student performance when ITS’ are used but the research does not explicitly discuss an increase in students’ conceptual understanding of math because it focuses on students pre- and post-test scores, and not on the instruction received. Currently, ITS’ test students’ knowledge through multiple choice questions, and assist students through their errors by providing scaffolded hints to help lead students to correct answer choices but there is not a focus on the concepts behind the correct answers.

As a mathematics consultant in New York City, who works in predominantly Black and Hispanic high schools, I witness time and again instruction that emphasizes mathematical procedures and basic skills, and lacks the opportunity for students to investigate and think critically about mathematics. Because teachers in these schools emphasize rote learning and teacher-directed instruction (Flores, 2007), it is important to provide a program that will emphasize mathematics concepts. ITS’, with the inclusion of an instructional component based on math concepts, have the potential to increase students’ access to quality, concept-based instruction. This study reports on a software program that focuses on conceptual instruction, rather than testing and correcting students to build their math knowledge. In an effort to expose students to instruction that builds their conceptual understanding of mathematics, I have created a student-facing, Common-Core aligned, algebra online learning program, MathConceptz. Unlike existing ITS’, the questions are built into the lessons and are designed to help students discover the learning of new concepts, rather than test their knowledge at the end of the lessons. The purpose of this study was to compare the impact of face-to-face and MathConceptz instruction on student performance in one unit of Algebra, as measured by students pre- and post-test scores.

In line with the literature on effective online learning programs, MathConceptz includes an interactive component through the use of scaffolding. Students engage in interactive lessons where they respond to scaffolded questions that activate their prior knowledge. Through the scaffolded questioning, students discover the concepts behind a math learning objective as opposed to the procedures. MathConceptz also takes into account the impact of student error on learning (Corbett & Anderson, 2001) and provides students with delayed feedback on errors. For the purpose of this study, students completed one Algebra module in MathConceptz, composed of eight lessons.

I employed a true experimental design across four schools. A total of five groups, consisting of 15 to 25 students, were chosen for the study. Each of the five groups was divided into three groups. Of the three groups, the first group received traditional face-to-face instruction from a teacher. The second group was a blended learning group that received traditional face-to-face instruction from a teacher and MathConceptz. The third group received instruction from MathConceptz, alone. All three groups received eight lessons on the same Algebra topics focused on linear and quadratic equations. Students in each group were administered an Algebra test, prior to and following to compare student scores across the three groups and observe the impact of MathConceptz on student learning. It was hoped that implementing this program in math instruction would improve students' mathematics performance. It was also hoped that an improvement in student performance would encourage teachers to implement the use of this technology more consistently, as well as, create mathematics lessons that are based primarily in math concepts.

The following research question and sub questions guided this quantitative study:

1) Does student performance improve from pre- to post-test after working with the online learning software?

a) How do pre- and post-test results compare from the face-to-face instruction group and the blended learning (face-to-face and existing ITS) group?

   Hypothesis: Students in the blended learning group will outscore the face-to-face instruction group at post-test controlling for pre-test.

b) How do pre- and post-test results compare between the face-to-face instruction group and the MathConceptz group?

Hypothesis: Students in MathConceptz group will outscore the face-to-face instruction group controlling for pre-test.

c) How do pre- and post-test results compare between the blended learning (face-to-face and MathConceptz) group and the MathConceptz group?

Hypothesis: Students in the MathConceptz group will outscore the blended learning group controlling for pre-test.

The following chapter provides an examination of the literature on the teaching of math conceptually in urban settings and the impact of intelligent tutoring systems on student achievement in math. The literature review is followed by the methodology, in which I describe the methods of the study and analysis of the study data. I then describe the results of the study and conclude with the implications of the study results on future research.

CHAPTER 2: LITERATURE REVIEW

As the focus of this study is on using an intelligent tutoring system to teach mathematics conceptually to low-income Black and Hispanic students, I review several areas of theory and research. My examination begins with an overview of the United States' position in science, technology, engineering, and mathematics (STEM), and the implications of the underrepresentation of minorities in STEM fields and how those implications have led to a shift from traditional mathematics instruction to mathematics instruction based on concepts. In the next section of this review, I define teaching math conceptually and examine the research base on how Whites and minorities have different access to this type of instruction, leading to the achievement gap. This review concludes with an examination of studies on intelligent tutoring systems and their impact on student performance. Throughout this review, I identify the limitations of the research base and explain how my research addresses some of these limitations.

STEM Education

The global need for highly trained STEM personnel creates a high demand for occupations in STEM fields (Koledoye et al., 2011). STEM occupations are amongst the highest paying and fastest growing in the nation (Thomasian, 2011) and there is an expectation that, during the next decade, the demand for STEM occupations will increase at four times the rate of all other occupations (Koledoye et al., 2011). STEM education provides a great foundation for economic success as individuals in these fields typically experience career flexibility, economic prosperity, and low unemployment rates (Thomasian, 2011). In order to compete and contribute in the global market, the United States needs highly trained citizens in science, technology, engineering, and mathematics (STEM). However, in the US, only 15% of all undergraduates receive their undergraduate degrees in STEM fields, compared to 67% of undergraduates in Singapore, 50% in China, 47% in France, and 38% in South Korea (Koledoye et al., 2011). In 2005, 15 year olds in the United States ranked 28th in math literacy and 24th in science literacy (Kuenzi, 2008), creating an appearance of inconsistency in the math and science achievement of US students when compared to other nations.

In considering STEM education, looking particularly at math education, taking an advanced math course during high school can predict graduation, college enrollment, early career earnings as well as influence growth in earnings later in adulthood more than any other subject (Rose & Betts, 2004; Mata et al., 2012; Siegler et al., 2012; Ali & Jameel, 2016). Enrollment in these courses has the potential to positively influence educational outcomes such as school completion, standardized test scores, and college performance. Students enrolled in advanced math courses have the opportunity to develop skills that they can apply directly to specific jobs, such as reasoning and logic skills that tend to make them more successful in those careers (Joensen & Nielsen, 2009; Rose & Betts, 2004). An overview of the research base shows the correlation between math performance and academic success. In a national education longitudinal study conducted in 1988, Rose (2006) found that gains in mathematics scores were positively correlated with high earnings as well as educational attainment. Students who scored relatively high in math tests during high school had relatively higher earnings compared with their counterparts who had low math test scores in high school (Arcidiacono, 2004; Rose, 2006; Rose & Betts, 2004; Joensen & Nielsen, 2009). Similarly, through employing ordinary least squares (OLS) regression with a focus on the impact of math scores on income from the National Longitudinal Study of Youth database, Oehrlein (2009) found that mathematics grades have a statistically significant impact on income (Joensen & Nielsen, 2009). This suggests that individuals with high mathematics skills are more likely to secure higher paying jobs than those with poor math skills irrespective of their field of specialty (Oehrlein, 2009), leading to the conclusion that individuals who have advanced math skills are likely to earn high salaries and experience career success in the future (Betts, 2006).

Not only does mathematics serve as a gatekeeper for future occupational and educational opportunities, but success in mathematics can also be an effective means of enhancing economic as well as social conditions for students, particularly students from disadvantaged backgrounds that are over-represented by Black and Hispanic students (Byun et al., 2015). Unfortunately, Black and Hispanics are underrepresented in STEM fields and, compared to Whites, are less academically prepared for STEM fields; this number is even less for Black and Hispanic students from disadvantaged backgrounds. Less than 15% of undergraduate degrees in STEM were earned by Black and Hispanic students (Koledoye et al., 2011). It seems that the lack of presence of Black and Hispanic students in STEM education and occupations stems from limited academic preparation (Koledoye et al., 2011; MacPhee et al., 2013).

Math Courses

Mathematical competence largely depends on the development of conceptual understanding as well as procedures. Conceptual understanding of math is mainly identified as explicit rich knowledge and can be defined as a connected web of knowledge linking discrete pieces of information (Llewellyn, 2012; Rittle-Johnson & Schneider, 2014; Kent & Foster, 2015), emphasizing the importance of the richness of the connections inherent in the knowledge (Star, 2005). A conceptual understanding allows students to apply and adapt acquired mathematical ideas to new situations (Balka et al., 2003) and develop enduring understandings of mathematics (Jackson & Wilson, 2012).

Students have the opportunity to adapt and apply a conceptual understanding of mathematics in mathematics classrooms that have normed practices around conceptual instruction. In a concept-based mathematics normed practices center around mathematical thinking. Mathematical thinking is characterized by understanding relations among multiple strategies, errors providing opportunities to reconceptualize a problem, and collaborative work involving reaching a consensus through mathematical argumentation, not simply a procedural description or summary (Kazemi & Stipek, 2001). Mathematics education researchers agree that to build students' conceptual understanding of mathematics, classroom practices should develop students' abilities to generalize from a solution, justify solutions, evaluate the reasonableness of solutions, and make connections among multiple representations of a mathematical idea (Jackson & Wilson, 2012).

The role of the teacher in a concept-based mathematics classroom is to support and guide the learning process rather than transmit discrete knowledge. This setting requires teachers to relinquish some control over mathematics activities and allow students to initiate their own strategies to solve problems and cope with contradictions (Stipek et al., 2001). Teachers ought to pose cognitively demanding tasks that require students to explain their reasoning, as well as encourage students to engage in whole class discussions of their solutions to rigorous mathematical problems (Balka et al., 2003). In addition, a conceptual understanding of mathematics requires students to generate connections between previous and existing knowledge. A possible poor domain of knowledge is likely to result in challenges in the understanding of mathematics. It is, therefore, necessary for teachers to possess deep content knowledge and the capability to pass this knowledge on successfully to students (Khan, 2012).

Math Instruction in Urban Schools

Unfortunately, urban schools tend to employ less qualified teachers than their suburban counterparts (Jacob, 2007; McKinney et al., 2007; Murnane & Steele, 2007; Walker, 2007; Battey, 2012; Adnot et al., 2017; Feng & Sass, 2018), exacerbating the issue of poor teacher quality in urban schools. Studies suggest that poor teacher quality is a leading cause of students' inability to engage in concept-based instruction. In fact, mathematics instruction for these marginalized populations tends to emphasize disconnected concepts and procedures, as opposed to explanations (Battey, 2012). As studies have suggested, concept-based instruction in math requires students to explain and apply their reasoning. However, a majority of students in urban settings find it challenging to understand or apply the concepts of mathematics within a real world context. This is largely attributed to the conventional instructional approach teachers in urban settings tend to utilize. The conventional approach in mathematics encourages students to perform math operations without necessarily reasoning through math problems (Lawler, 2016). This approach fails to enhance students' capabilities to understand math within a real-world context. An experimental study investigated the issue of whether a contextual instructional approach (an approach in which teachers present information in a way that students are able to construct meaning based on their own experiences), can enhance math conceptual understanding as well as problem-solving skills. A pre- and post-test was used to compare the conceptual understanding capability among students. The findings revealed that a contextual learning approach considerably impacted student conceptual understanding as well as the capability of students to solve problems in math (Punaji &

Dedi, 2017). Similarly, the Quasar project, an alternative to the conventional approach oriented toward helping students develop a meaningful understanding of mathematical ideas (Silver & Stein, 1996), found that teaching focused on problem solving and student thinking resulted in higher test scores for students in urban schools (Battey, 2012). As such, it is important to encourage conceptual understanding as a means of assisting students to enhance their understanding and enthusiasm in mathematics, showing the shifts involve teachers and students no longer viewing mathematics learning as memorization and rules, but more as problem solving (Lubienski, 2002).

Several reasons have been cited for the problem of poor teacher quality in urban settings. One reason cited is the high percentage of teacher vacancies in urban schools. A majority of urban schools face retention and recruitment issues of qualified teachers (Tai et al., 2007), as evidenced in a study by Anderson (2014), which revealed that 54% of urban schools have job openings for mathematics teachers with 41% of those schools reporting challenges in filling these positions. Teacher shortages, as a result of the difficulties experienced in filling mathematics positions with qualified teachers, leads to urban schools filling the available vacancies with less qualified teachers (Jacob, 2007; Anderson, 2014) and worsening the already existing problem of poor teacher quality (Feng & Sass, 2018).

Recruiting, training, and retaining quality math teachers in urban settings are critical problems in these schools that serve marginalized populations. The alternative pathways through which teachers in these settings are trained are thought, by some educators, to move math teachers into teaching on a fast track shortchanging them of the training necessary to adequately prepare math teachers for the classroom. Though teacher preparation programs create an avenue to attract strong candidates who majored in STEM fields, research shows that teachers tend to use the teaching methods they were taught in their K-12 education, instead of the practices they learned in the one-year training program (Newton et al., 2010). Students in urban schools tend to have teachers that have lower mathematics test scores, less experience, certification outside of mathematics, initially failed certification exams, and lower Mathematical Knowledge for Teaching (Loeb & Reininger, 2004; Strutchens et al., 2004; Hill et al., 2005). Scholars suggest that exposing teacher education candidates to predominantly black or culturally diverse settings is important to alleviating limiting pedagogy for non-white students (Walker, 2007).

Algebra, in particular, is a key course in the high school mathematics sequence making it a constant focus of research and policy. It has been touted as a determinant of future academic success, and serves as a gatekeeper to advanced courses in secondary mathematics (Hegedus et al., 2015; Simzar et al., 2016; Heissel, 2017; Litke, 2019, Tidd et al., 2019). Because of the role in Algebra in the secondary mathematics sequence, state and local policies have aimed to increase access to Algebra in schools with marginalized populations (Nomi, 2016; Litke, 2019). For example, “Algebra for All” is one such initiative with the focus of increasing underserved students’ exposure to Algebra (Nomi, 2016). Student understanding of Algebra relies on a nature of Algebra instruction that is focused on building concepts, procedural fluency, and problem solving (Litske, 2019; Tidd et al., 2019). Algebra instruction focuses on functions, relationships, patterns, and modeling of real-world contexts, and requires students to transfer knowledge to new contexts. It is important that Algebra instruction adopt a student-centered, inquiry-based model in order to build students’ conceptual understanding of Algebra while incorporating procedural fluency.

Unfortunately, despite the shifts in standards and curriculum Algebra instruction continues to emphasize teacher-centered instruction in which teachers control the delivery of mathematical content and ideas. In a case study of 108 ninth-grade Algebra lessons, a newly developed algebra-focused observation tool was used to rate the quality of instruction as observed through the videos of lessons. The study found that the instruction in the sample was primarily teacher-directed and included minimal student participation and engagement with mathematical ideas (Litke, 2019), showing that the focus of Algebra instruction continues to emphasize procedures and teacher direction, to the detriment of student learning. Romberg (1998) described the typical math classroom as a pattern involving reviewing homework, teacher explanation and examples of a new problem type, and students engaging in independent practice focused on the new problem type. The typical classroom concludes with the teacher summarizing the work and a teacher-led question-and-answer period. This may be in part due to the belief of many Algebra teachers in middle school and lower high school grades that their students lack the foundational understandings needed to access Algebra. For example, Algebra teachers tend to believe that before students can access the abstract and symbolic world of Algebra, students must be well-versed in multiplication, fractions, and integer operations (Koirala & Goodwin, 200; Henry, 2001). Similarly, according to Kaput (1999), the traditional image of Algebra is characterized by learning the rules for simplifying expressions, solving equations, and manipulating symbols; basically a set of procedures disconnected from other mathematical concepts and students' real worlds.

The typical Algebra classroom teaching structure goes against the research, which suggests the most effective methods of teaching Algebra are modeling, systematic, heuristic, and guided discovery. More specifically, direct instruction, problem-based learning, and manipulatives, modeling, and multiple representations have been found to be the most effective methods of teaching Algebra. In a meta-analysis of 35 independent experimental studies results shows that the aforementioned teaching strategies have positive effects on student achievement in the secondary Algebra classroom. Specifically, the meta-analysis found that direct instruction, defined as a teaching method that encompasses all the others as it focuses instruction on an objective while assessing and providing feedback on student progress, had the largest effect for low-ability and high-ability students. Problem-based learning, a method that provides a context for learning and creates situations where students actively construct their knowledge of Algebra and encourages multiple approaches and solutions, had the second largest impact. Lastly, multiple representations, best defined as a hands-on approach had the third largest impact (Haas, 2005).

Online Learning

Online learning is among the fast-growing trends in Technology Enhanced Learning (TEL) (Dichev, Dicheva, Agre, and Angelova, 2013; Lee, 2014; Ichinose & Bonsangue, 2016) and has been identified as one possible solution to the problem of teacher quality in K-12 mathematics education (Smith et al., 2005; Cascaval et al., 2007). For the past several years, schools have moved from traditional education to online learning as it enables learning to take place under the learner's control and promotes differentiated instruction, instruction where teachers react to each learner's needs and value is given to all students' learning styles (Marlowe, 2012), suggesting that it may be beneficial for learners with a broad range of academic needs and allow teachers to offer individualized instruction to meet the precise needs of individual students (Chaney, Chaney, & Eddy, 2010). In addition, because online learning provides students opportunities to access education regardless of their geographical location, it may be a promising method of promoting equity by offering students access to courses that would have otherwise been inaccessible, particularly in urban areas (Dichev, Dicheva, Agre, and Angelova, 2013).

Because of its autonomous nature, the online learning setting has the potential to motivate student learning when compared to a face-to-face classroom setting. The autonomous nature of online learning provides students experiencing difficulties in a classroom setting the opportunity of alternative methods of acquiring new and deeper understandings of content (Ichinose & Bonsangue, 2016). In fact, Spence (2007) reported that at the 19th International Conference on Technology in Collegiate Mathematics, students chose to participate in an online mathematics course to avoid the face-to-face interactions that they tend to find uncomfortable. In a study that examined students' self-related mathematics beliefs in an online setting compared to a face-to-face setting, the survey responses of 2,051 high school students and 271,323 students administered the PISA exam were examined to determine students' self-related mathematics beliefs as measured by a Likert scale. Study results showed that students in an online course reported higher levels of mathematics self-efficacy when compared to the face-to-face group, suggesting that online learning has the potential to decrease student discomfort while learning math and increase their motivation when learning mathematics (Ichinose & Bonsangue, 2016). Similarly studies in turnaround schools, found the benefits of online learning in low-performing schools to include potentially motivating students (Corry & Carlson-Bancroft, 2014). In an analysis of data from interviews, think aloud observations, and online focus groups of 16 undergraduate students, Armstrong (2016) found that students mainly pursued online education because of the flexibility and self-control within the learning environment that it offers. Furthermore, in a study involving 20 low-performing ninth grade students, participants believed they were successful in their online credit recovery courses because they were able to move at their own pace, as opposed to feeling rushed and, as a result, confused in a traditional classroom setting (Jones, 2011).

Educational researchers advocate the importance of using the Internet's learning resources to inspire algebra classrooms for middle school students and to reinforce the learning of its concepts (Alsaeed, 2017). In Algebra, it is important that students are able to draw connections between relationships among symbols and representations of algebraic operations. Research suggests that interactive tools are able to help students discover and verify these relationships and representations. In addition, virtual manipulatives assist students in building a conceptual understanding of algebraic concepts. In fact, several studies found that the use of computers to improve students higher order thinking skills was positively correlated with student achievement in math (Cavanaugh et al., 2008). For example, in a quasi-experimental study that examined the effect that an online Algebra initiative had on student outcomes, it was found that the students in the online Algebra course scored higher on their post-tests than the control group. Additionally, the students in the online course scored higher specifically on test items related to making real-world connections, as is important to building a conceptual understanding of math (O'Dwyer et al., 2007).

Many of the online representations of Algebra are designed to use animations and representations to make connections between mathematical concepts and procedures (Tidd et al., 2019). In a study that used random assignment to compared the impact of a virtual Algebra I course on student to a traditional in-class Algebra I course to eighth grade math classes, found that providing a virtual Algebra I course to eighth-grade students improved their Algebra knowledge at the end of eighth grade, in comparison to the control students. Students in the virtual course were also more likely to pursue an advanced course sequence in ninth and tenth grade (Heppen et al., 2011). Similarly, in two studies, one a cluster randomized trial and the second a quasi-experimental study, that evaluated the impact of replacing traditional Algebra II curriculum with interactive software and technology-enhanced curriculum, researchers found that the virtual component had a significant impact on student learning of core algebra concepts including both procedural and conceptual problems (Hegedus et al., 2015).

As online promises the possibility of a quality education for all students regardless of time and location, it may open educational pathways for students in urban areas or low socioeconomic schools districts. As such, online learning has been identified as one possible solution to the problem of teacher quality in K-12 education, particularly in mathematics (Smith et al., 2005;

Cascaval et al., 2007). Studies have shown that online learning has a positive impact on math achievement (Chappell, Arnold, Nunnery, & Grant, 2015), especially on middle school algebra achievement among students (Russell, Kleiman, Carey, & Douglas, 2009). In a program evaluation study that explored the effect of an online mathematics tutoring program on student's achievement across 15 elementary schools, students were enrolled in the Math Whizz program as a supplement to math instruction for one school year. Findings revealed that Math Whizz usage was positively related to improved mathematics achievement among students (Clark & Whetstone, 2014). Similarly, Chappell, Arnold, Nunnery, and Grant (2015) found that online learning has a positive effect on struggling learners' mathematics achievement. This is mainly attributed to online learning's capability to facilitate instructional explicitness, which is an effective intervention among students that have mathematics difficulties. These studies suggest that online learning can be used to address student deficiencies in math that are a result of poor teacher quality (Chappell et al., 2015; AbuEloun & Naser, 2017).

Intelligent Tutoring Systems

One form of online learning that can be used to address student deficiencies are intelligent tutoring systems (ITS). ITS' are artificial intelligence technologies that enable computers to assume the role of a teacher. They are intended to deliver personalized instruction to students with distinct needs for the purpose of transferring knowledge (Freedman, Ali, & McRoy, 2000). ITS' deliver personalized instruction by adapting to the needs of individual users through problem selection, and offering customized instruction and formative feedback on correct responses and possible error without human intervention. ITS' aim to enhance long-distance learning by incorporating web-based systems in their central servers that allow students to learn in their own environment, making ITS instructional materials accessible both at home and via computers (Chien, 2008; Huang, Craig, Xie, Graesser, & Hu, 2016) .

Focusing on math, research suggests that ITS' in mathematics assist students of all ages in understanding the basics of math content, while improving long-distance learning and complementing traditional classroom teaching. Several benefits of ITS' have been cited, one of which being that ITS' allow students to learn within their own setting at their own pace (AbuEloun & Naser, 2017). ITS' tend to present a level of reasoning and knowledge similar to human tutors, resulting in systems that generate useful feedback to students. ITS' also cultivate a high order of thinking and provide students with a motivating learning environment, all of which results in a positive impact on student attainment in Algebra (Chen, MdYunus, Ali, & Bakar, 2008). For example, Chien, Yunus, Suraya, Ali, and Bakar (2008) conducted an experimental study on the impact of an ITS on student achievement focused around algebraic expressions. Two groups of students were enrolled in the study. One group consisted of 32 students who studied algebraic expressions within a computer-assisted instruction learning environment whereas the other group of 30 students studied within a computer-assisted instruction learning environment and ITS. The findings indicated that there were statistically significant differences in students' achievement in the topic of algebraic expressions. Students who learned in the computer-assisted instruction and ITS environment demonstrated better performance in comparison to their counterparts using solely computer-assisted instruction, suggesting that ITS' are effective in assisting students in learning algebraic expressions, a foundational topic in Algebra (Chien et al., 2008).

Furthermore, in a meta-analysis review of 34 studies on the effectiveness of ITS', findings indicated that the implementation of an ITS raised overall test scores by approximately 0.35

standard deviations. The test scores for students learning with an ITS were higher than those who did not receive instruction from the ITS (Steenbergen-Hu & Cooper, 2014). Similarly, another meta-analysis analyzing a total of 73 reports found that, when compared to teacher-led and large group-based instruction, the use of an ITS resulted in greater student achievement (Ma, Adesope, Nesbit, & Liu, 2014). As shown by these studies, interaction with ITS' tend to result in greater student achievement than participating in a traditional classroom setting, primarily, because of the attributes of ITS'. ITS' provide greater interactivity with the user and more engaging means of instructional presentation. In addition, the feedback from ITS' tends to be more response-specific, hence facilitating greater student cognitive engagement.

Along with raising test scores, ITS' have also been shown to improve student motivation toward learning. In a study testing the effect of an ITS, ALEKS, on reducing racial/ethnic gaps in an after school program amongst 6th grade students, results showed that students who participated in the program outperformed students who did not participate in the after-school program. Also, the students in ALEKS classrooms required significantly less assistance from teachers to complete their daily work than students in teacher-led classrooms, and reported more positive attitudes toward learning math (Huang et al., 2016). As such, it seems ITS' have the capability to not only address the issue of poor teacher quality, but also positively impact student performance and motivation toward learning.

The ability of ITS' to improve student performance stems from their features. ITS' provide aspects of enhanced student control, individualized task selection, individualized comments to students, as well as more opportunity for practice (Steenbergen-Hu and Cooper, 2014). ITS' also allow students to ask questions, as well as, request the tutoring system to demonstrate the key steps that are required to begin and solve a particular mathematical problem. The ITS, in turn, offers context-specific solutions to students' questions concerning concepts or their applications. This enables students to obtain assistance on a specific problem that they are currently working on. The system presents students with an opportunity to practice math problems, while accessing instant feedback on an unlimited number of algorithmically generated problems (Phillips & Johnson, 2011). ITS' assess student knowledge in a systematic manner and provide customized instruction based on students' skill levels, while generating feedback for both teachers and students (Cen, 2009).

The functionality of ITS' stem from their domain model, which is a conceptual model that incorporates both a behaviour and data representation of meaningful real-world concepts pertinent to the domain that need to be modeled in software. ITS' include a user model that maintains comprehensive records of students' problem solving behaviors, as well as, estimates what students understand within the given domain by constantly updating the user model as students navigate the system. With the presence of a cognitive profile of each learner, ITS' adapt their functionality by displaying a broad range of assistance hints (Beal, 2004; Chien et al., 2008). ITS' in mathematics are characterized by the provision of electronic-based forms, simulated instrument panels, and other user interfaces that enable students to enter the steps needed to solve a given mathematical problem. The systems then provide hints after each step is entered. In some ITS', the system may provide a hint after the student has submitted his or her solution and then marks individual steps as correct or incorrect. The system then conducts a debriefing to facilitate a discussion of specific steps with the student (VanLehn, 2011). AnimalWatch, Math Whizz, Cognitive Tutor, and ALEKS are examples of intelligent tutoring systems that have improved student math performance as a result of their ability to build a cognitive profile of each user, provide assistance hints, and facilitate a discussion with the user of specific steps (Beal et al., 2010; Clark & Whetstone, 2014; Huang et al., 2016).

ITS' can, however, inhibit learning in the event that students utilize them merely to provide shortcuts to a given solution instead of as a means of enriching their learning process (Phillips & Johnson, 2011). A study by Erdemir and Ingeç (2016) assessed mathematics teachers' perceptions of intelligent tutoring systems with regard to their usability and impact on student understanding of math concepts. The study involved 43 student participants in a mathematics teaching program. Data obtained using a paper-based survey showed that participants experienced difficulties in understanding math concepts. Yaratan (2003) furthered that there are instructional issues with ITS', attributed to the fact that students only gain procedural knowledge from use of these systems. In alignment with Yaratan's (2003) findings, an analysis of The Cognitive Tutor revealed that the curriculum is based on a theoretical, not conceptual foundation, applies the basic theory to the particular domain and objectives of interest, evaluates results, and develops and implements a methodology for improving the curriculum on the basis of use (Ritter et al., 2007). As such, the students have minimal chance to learn and practice the main concepts in mathematics.

To date, there is very limited research on the impact of ITS' when comparing student performance as a result of receiving instruction from an ITS in comparison to face-to-face instruction. The closest study is one quasi-experimental design that compared the academic outcomes of students in a blended model (face-to-face instruction and an ITS) with students receiving instruction from an ITS, only. In this study a total of 1,332 college students, from one college and enrolled in a ten-week Pre-Calculus course, took either a blended course (face-to-face instruction with an online component through ALEKS) or received instruction through ALEKS alone. Results showed that students in the blended learning group outscored students in online group as measured by student scores on a paper-based final exam, ALEKS final exam, and final course grade. Possible reasons for this result can be the amount of time students spent on ALEKS in comparison to the time spent engaging in face-to-face instruction, and the weight of the ALEKS component on students' final course grade in the blended learning group (Cung et al., 2019).

In summary, the research indicates that the positive impact that ITS' have on student math achievement make it a viable solution to the issue of poor teacher quality in urban settings. However, the research does suggest that current ITS' may not be effective in building students' conceptual understanding of math. Little is known about how ITS', alone, impact student achievement in comparison to face-to-face instruction. This study addresses the research gaps by examining whether instruction from only an ITS that teaches math conceptually will have a greater impact on student performance in Algebra than face-to-face instruction, alone, or a blended learning setting. Currently, no studies have compared student outcomes between instruction from an ITS and face-to-face instruction. Therefore, the findings of this study will have important implications for mathematics educators who are considering replacing face-to-face instruction with ITS' or incorporating ITS' in mathematics instruction.

CHAPTER 3: METHODOLOGY

This study tested the hypothesis that students who work with an intelligent tutoring system, Math Conceptz, have greater improvement from pre-test to a post-test in Algebra compared to students who receive face-to-face instruction and blended learning instruction in Algebra. The research question that guided this study was:

Does student performance improve more from pre- to post-test for students working with the online learning software than for students receiving more traditional instruction?

Three hypotheses were put forward regarding the expected findings:

Hypothesis 1: Students in the blended learning group outscore the face-to-face instruction group at post-test controlling for the pre-test.

Hypothesis 2: Students in the MathConceptz group outscore the face-to-face instruction group at post-test controlling for the pre-test.

Hypothesis 3: Students in the MathConceptz group outscore the blended learning group at post-test controlling for the pre-test.

Participants

Student participants were selected from four schools, in which I coach, in the New York metropolitan area at the beginning of the study. The schools (Edson School, Unified School, Solomon Academy, and Anderson School) are located in low-income areas and serve predominantly Black and Hispanic populations. Each school has a computer lab with at least 30 desktop computers, and at least two class sets of 30 laptops, allowing for each student to have a personal laptop for the study. The test groups consisted of 8th and 9th-grade students because math standards for these grades focus heavily on Algebra, as does the MathConceptz unit.

For the study, a total of 79 students across the four schools were selected to participate. Approximately 15, 8th and 9th-grade students from each school were chosen using stratified random sampling. Stratified random sampling classifies or separates people into groups, referred to as subsets or subgroups, according to some characteristics, such as position, rank, income, education, sex, or ethnic background. A random sample is selected from each stratum based upon the percentage that each subgroup represents in the population (Creswell & Creswell, 2018). To generate similar samples, in each school, all 8th or 9th-grade students, excluding English Language Learners (ELLs) and students with Individual Education Programs (IEPs), were given permission slips, as shown in Appendix C, to obtain written informed consent from their parents to participate in the study. In each school, the students who returned the permission slips were divided into two groups, male and female, with an equal number of students in each group, to be placed in one of the three study groups. There was an almost equal number of males and females chosen, approximately 8 boys and 7 girls per school, to reduce variation in gender, ethnicity, and free or reduced lunch.

To choose the approximately 15 students at each school, I created two groups. Group A was the group of male students that returned their permission slips, and Group B was the group of female students that returned their permission slips. For Groups A and B, I created a list of student names, in alphabetical order by last name, and assigned an individual number to each student. I then used a random number generator to choose approximately 5 students from Group A and approximately 5 students from Group B. A number generator was downloaded from Google.com and, for each group, I placed the value “1” in the minimum space and the number of students who returned the permission slips in the maximum space. For each group, I selected "Generate" and wrote down the first 5 numbers that were generated. I then aligned the values I generated to the student names and used those students as the study sample at each school. I again used a stratified random assignment to divide the approximately 15 selected students from each school into the three test groups. I numbered the list of student names from 1 to 15. I used the number generator to randomly select an equal number of students for Groups 1, 2, and 3. Table 1 provides a description of the students selected for the study.

Table 1

Number of Students in Study Groups for Each School

School	Groups	Number of Male Students	Number of Female Students
School 1	Group 1	3	3
	Group 2	4	3
	Group 3	3	3
School 2	Group 1	6	2
	Group 2	3	5
	Group 3	2	5
School 3 (Teacher A)	Group 1	2	3
	Group 2	3	3
	Group 3	3	3
School 3 (Teacher C)	Group 1	1	2
	Group 2	2	1
	Group 3	2	2
School 4	Group 1	2	2
	Group 2	2	1
	Group 3	1	2

Teacher participants were selected using convenience sampling. A convenience sample is a type of non-probability sampling method where the sample is taken from a group of people easy to contact or to reach (Creswell & Creswell, 2018). Four of the schools in the experiment have only one Algebra teacher per school, while one school has two Algebra teachers. The Algebra teachers facilitated the face-to-face instruction and blended learning portions of the study. As can be seen in Table 2, the 5 teachers range in years of teaching experience, Masters degrees, and certifications.Table 2 provides a description of the teachers in the sample.

Table 2

Sample Teacher Qualifications and Years of Experience

Teacher	**Degree**	**Certification**	**Years Teaching Math**
A	M.S. Technology Management; MBA in Finance; M.S. in Applied Mathematics	Sixth Year Certificate of Advanced Study - Secondary Math	5
B	M.S. in Literacy; M.S. in School Building Leadership	Literacy; Childhood Education	16
C	M.S. Learning Technology	Secondary Math Education (7-12)	24
D	M.S. in Educational Leadership and Policy Studies	Secondary Math Education (7-12)	8
E	M.S. in Secondary Math Education - In progress	Secondary Math Education (7-12) - In progress	2

Research Design

The experimental design consisted of a one-way, three-group design comparing pre- and post-test data between students receiving face-to-face instruction, face-to-face instruction and MathConceptz instruction, and MathConceptz instruction only. This study utilized a true experimental design as the participants in each school were randomly assigned to one of three groups to test the impact of the MathConceptz program on student performance as measured by a pre- and post-test (Creswell, 2009). The control group, Group 1, received face-to-face instruction. The experimental groups were Groups 2 and 3. Group 2 served as the blended learning group and received face-to-face instruction and MathConceptz instruction. Group 3 received MathConceptz instruction only. The primary outcome measure was student performance. I measured student performance by comparing students' pre- and post-test scores on a unit exam that tests students' knowledge of linear and exponential functions. Table 3 provides a description of the content of the MathConceptz lessons.

Table 3

Description of MathConceptz Lessons

Lesson	**Objective**	**Visual Component**
1	SWBAT solve two-step algebraic equations.	Students learn to solve equations by using a balance beam to determine the number of cookies in a bag, which represents a variable.
2	SWBAT solve multi-step algebraic equations.	Students learn to solve equations by using a balance beam to determine the number of cookies in a bag, which represents a variable.
3	SWBAT multiply binomials.	Students learn to multiply binomials by creating rectangles with algebra tiles.
4	SWBAT factor trinomials with positive coefficients into two binomials.	Students learn to factor trinomials by finding the length and width of

		rectangles, using algebra tiles.
5	SWBAT factor trinomials with negative coefficients into two binomials.	Students learn to factor trinomials by finding the length and width of rectangles, using algebra tiles.
6	SWBAT use patterns to factor trinomials algebraically.	Students learn to factor trinomials by identifying patterns in the relationship between the coefficients in the trinomials.
7	SWBAT find the zeros of a quadratic function using the graph of quadratic functions.	Students learn to identify the zeros of a quadratic function from the graph of the function on a coordinate grid.
8	SWBAT find the zeros of a quadratic function algebraically.	Students learn to find the zeros of a quadratic function by identifying the relationship between the graph and the equations of a quadratic function.

Procedure

Pre-study. The pre-study phase consisted of three parts: obtaining permission from teachers, students, and parents to participate in the study, facilitating teacher introductory meetings and teacher training, and assessing teacher quality and student algebra knowledge. During the pre-study, I first got permission from each Algebra teacher to participate in the study. I also got parental consent allowing their child to participate in the study, as well as student assent to participate in the study. Teachers then viewed the MathConceptz tutorial and addressed questions they had after their first viewing. Teachers also completed three modules to ensure that they are familiar with the design and content of MathConceptz.

Second, I met with each teacher individually after school to discuss the purpose of the study and their role in the study, as well as train them on MathConceptz. Teachers were informed that they were teaching eight, 15-minute sessions, focused on linear and quadratic equations, to two different groups of ten 8th or 9th-grade students, as well as monitoring the use of MathConceptz for one group of students. They also administered previously created pre- and post-tests to their groups. Their commitment to the study was 10 days. Each school designated one class period per day for the study. Teachers used this class period to administer the pre-test on day 1, facilitate eight sessions on days 2-9, and administer the post-test on day 10.

Third, I measured teacher quality and assessed student Algebra knowledge before the study. Since this study measured the impact of MathConceptz instruction against face-to-face instruction, I used the Charlotte Danielson rubric to measure teacher quality to determine whether the level of the program's impact on student performance is correlated in any way with teacher quality. Also, I used the previous year’s teacher evaluations to calculate each teacher’s average evaluation rating.

Lastly, students were administered pre-tests to assess their Algebra knowledge prior to the intervention. Before administering the pre-tests, teachers were given a list of the participating students and their designated groups. Each group took the pre-test on their first day. The exams were proctored by the Algebra teacher participating in the study during the Algebra class period. Students had 30 minutes to complete the exam. The exam was administered by paper and students used a scantron to fill in their exam responses. At the end of the 30 minutes, teachers collected the exam and scantrons. Scantrons and exams were placed in a folder labeled with pre-test, the date, student identification number, and group number.

Intervention. The intervention phase took place during days 2-9 and included students in Groups 1, 2, and 3 receiving instruction that was either face-to-face, through MathConceptz, or a combination of both. On days 2 through 9, each group received 15 minutes of either face-to-face or

MathConceptz instruction, and an additional 15 minutes of independent practice. Groups received 15-minute lessons to accurately compare MathConceptz instruction to teacher-led instruction. By leaving the instruction to 15 minutes, I ensured that students were not receiving additional instruction from teachers during the Do Now, Guided Practice, or Work Period phases of the lesson.

Each lesson was aligned to the Common Core standards, 8.EE.C.7, A.APR.A.1, and A.APR.B.3, which focus on solving linear equations, multiplying binomials, factoring quadratic equations, and identifying the roots of quadratic functions. The modules for this study focused on these standards because these are units that students are not yet exposed to at the beginning of an Algebra course. Group 1 received 15-minutes of face-to-face instruction. At the start of the lesson, the teachers set a 15-minute timer and closed the lesson at the end of the 15 minutes. Students in Group 1 used an additional 15 minutes to complete independent practice problems created by the Algebra teacher.

In each school, Group 2 received 15 minutes of face-to-face instruction with Group 1, and 15 minutes of instruction from MathConceptz with Group 3. The MathConceptz lessons were available for student use on the laptops, which were provided by each school. At the beginning of the school day, I laid out the MathConceptz lessons on each laptop. Students did not need login information to engage in the modules. At the beginning of the face-to-face portion of the lesson, the teacher set a 15-minute timer and closed that portion of the lesson at the end of the 15 minutes. Students then received instruction from Math Conceptz. The MathConceptz lessons were aligned to the same Common Core standards, 8.EE.C.7, A.APR.A.1, and A.APR.B.3, as the face-to-face lessons. MathConceptz lessons utilize visuals, scaffolded questions, and error monitoring to encourage student discovery of the learning. The teacher set a 15-minute timer to provide students with 15 minutes to engage with one lesson of instruction from MathConceptz. Group 3 received 15 minutes of instruction from MathConceptz. Similar to Group 2, the students in Group 3 engaged in MathConceptz instruction aligned to standards 8.EE.C.7, A.APR.A.1, and A.APR.B.3. The teacher set a 15-minute timer to provide students with 15 minutes to engage with one lesson of instruction from MathConceptz. All students accross the four schools completed the same lesson for each day of the intervention. Students in Group 3 then completed independent practice problems, for an additional 15 minutes, created by the Algebra teacher.

Post-intervention. The post-intervention phase included the post-test. On day 10 for each group, students took the post-test. The exams were proctored by the Algebra teacher. Students had 30 minutes to complete the exam. The exam was administered by paper and students used a scantron to fill in their exam responses. At the end of the 30 minutes, teachers collected the exam and scantrons. Scantrons and exams were placed in a folder labeled with post-test, the date, and group number. The overall research design is summarized in Figure 1 below.

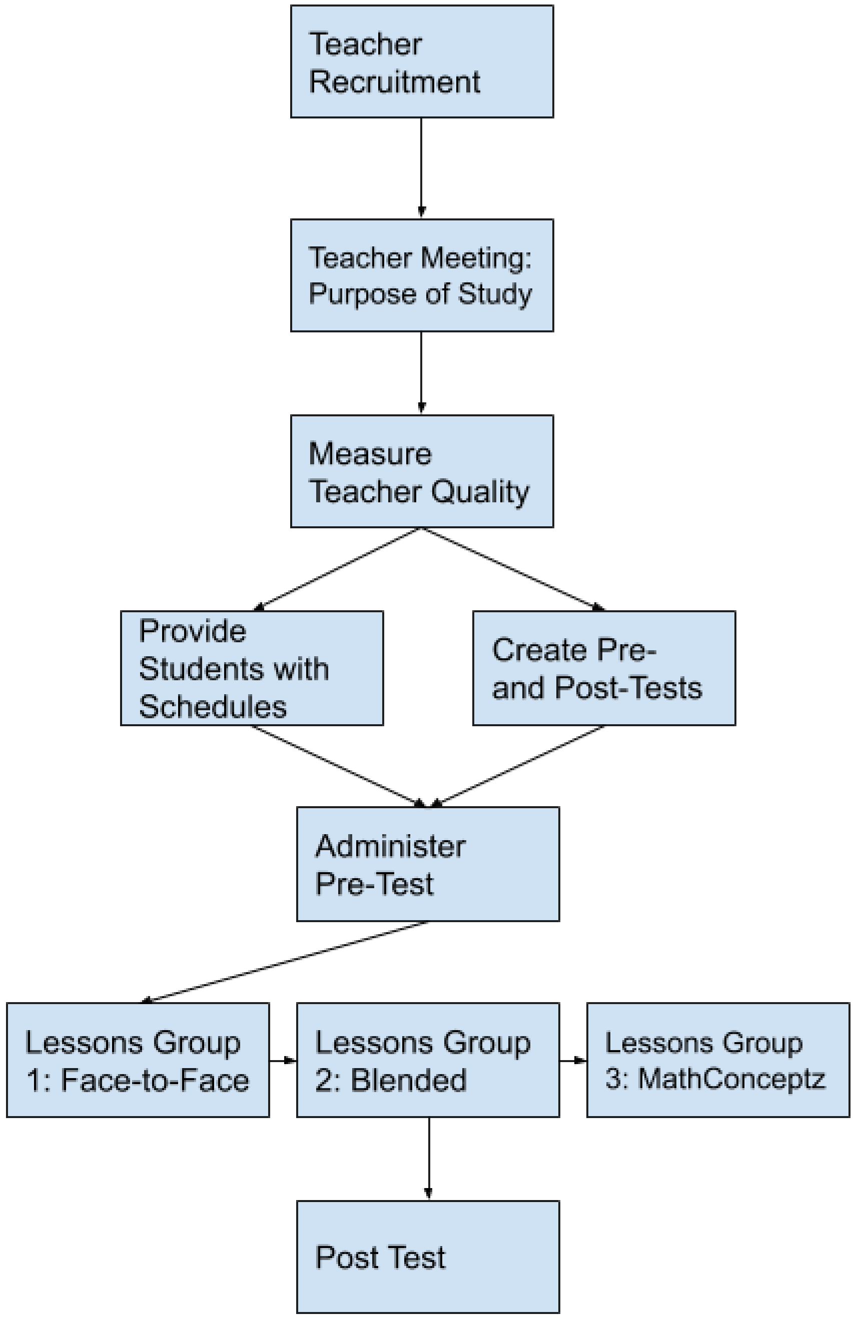

Figure 1. Study research design.

Data Collection

To examine the impact of MathConceptz on student algebraic learning, I collected 3 types of data that included student demographics, a measure of teacher quality, and student pre- and post-test measures of mathematical learning.

Student demographics. I collected administrative data on student demographics from each school's student information reports. This data consisted of socio-demographic information, including race/ethnicity, gender, and socio-economic status (SES), as indicated by eligibility for the federal free or reduced-price meal program (FRL). Each student was given an identification number that only I, the researcher, knew. This identification number was used for all future analyses. I created an excel spreadsheet that listed students by identification number and included the columns, "School," "Treatment Group", "Teacher quality scores", "Race/Ethnicity," "Gender," and "SES" to store their demographic data. This data was collected to shed light on whether there was a relationship between students' race, gender, and SES, and the impact of MathConceptz on student performance.

Teacher instructional quality. I also collected data on teacher performance as measured by the Charlotte Danielson rubric, components 3a-3d. The Charlotte Danielson Framework for Teaching is a research-based set of components of instruction, aligned to the Interstate Teacher Assessment and Support Consortium (InTASC) standards, and grounded in a constructivist view of learning and teaching. The framework is divided into 22 components (and 76 smaller elements) clustered into four domains of teaching responsibility. The Danielson rubric rates teaching on a 4-point scale of ineffective, developing, effective, and highly effective. The rubric describes key attributes for each rating.

I observed each teacher participant for 15 minutes during one mini-lesson because that was the focus of the study. During the observation, I took low-inference notes on teachers' statements and actions. I rated teacher practice according to Domain 3, components 3a-d (Communicating with Students, Using Questioning and Discussion Techniques, Engaging Students in Learning, and Using Assessment in Instruction) as these components relate to the implementation of classroom instruction in Algebra. I also collected the previous year's teacher evaluation data from the principals of each school. I used my rating of the teacher and the teacher's previous year's ratings to calculate the average rating for each teacher. I created separate electronic folders for each teacher. Each teacher had a file for their observation ratings. This data was used to determine the level of impact, if any, that MathConceptz had on student performance when compared to teacher quality, as measured by the Danielson Rubric shown in Appendix D.

Measures of mathematics learning. Pre- and post-tests were used to assess students' Algebra knowledge before and after the intervention. Tests consisted of Common Core Regents Examination and Illustrative Mathematics questions that are aligned to the standards, 8.EE.C.7, A.APR.A.1, and A.APR.B.3, being covered in the intervention lessons. Questions were chosen from the Common Core Regents Examinations and Illustrative Mathematics as these questions assess students' conceptual understanding of math and the ability to apply their knowledge in multiple contexts. The pre- and post-tests consisted of 8 multiple choice questions and 2 short response questions. As shown in Appendix E the post-test has the same questions as the pre-test, but the numerical values in the questions are different. I collected students' pre- and post-tests on Days 1 and 10 of the program. Tests were graded using the IO Assessment. IO Assessment allows tests to be graded by scanning individual student scantrons, and displays test scores sorted by class and individual students on an Excel spreadsheet. I created separate electronic folders for each group labeled with either pre- or post-test, the date, and group number. The test data from the pre- and post-test scores were used to determine the impact, if any, that MathConceptz had on students' performance. With the data from IO assessment I was able to compare pre- and post-test data not only by overall scores but also by specific skills and standards.

Role of the Researcher

In this study, there were three parts to the role of the researcher: Training teachers on MathConceptz and their role in the study, monitoring student and teacher actions in the classroom, and providing teachers with feedback focused on how they were maintaining fidelity to the study. As a researcher, my role was to train teachers on MathConceptz. During the preliminary meeting with the teachers, they engaged with the MathConceptz module. I was present to answer questions or address any concerns they had with using the program. My role also included monitoring student and teacher actions in the study. This included ensuring that teachers remained within the designated instructional time frame and maintained a neutral role by not providing students with assistance through the modules. It also involved ensuring that students worked through the modules independently. Lastly, as a researcher, I provided teachers feedback to ensure fidelity to the study. Feedback was focused on, but not limited to fidelity to time constraints and monitoring of students’ use of the software. For example, in each school on Day 1, I noticed that teachers were assisting students during the 15-minute work time following the mini-lesson. I instructed teachers to make sure that they only instructed students for 15 minutes and allowed students to work independently for the remainder of the time.

Threats to Validity

Internal validity threats. Internal threats to validity include selection, cross-contamination of groups, testing, and instrumentation. Selection refers to the selection of participants who have certain characteristics that predisposes them to have certain outcomes (Creswell & Creswell, 2018). For example, the students in the experiment are not of the same academic level. Students' academic levels may affect their performance on the pre- and post-tests. Random assignment may help to minimize this threat because the makeup of each group consists of a mixture of student backgrounds.

Cross-contamination of groups may impact students' familiarity with the tests. Cross-contamination of groups occurs when participants in all groups communicate with each other, which may influence each of the groups' performance on the pre- and post-tests. Cross-contamination of testing also poses a threat to validity, as participants may become familiar with the outcome measure and remember responses for future testing (Creswell & Creswell, 2018). To minimize these threats, the questions on the pre-test were reordered for the post-test. While the tests included the same questions, the order of the questions changed from pre- to post-test.

Instrumentation poses a potential threat to validity as there were changes between the pre- and post-tests (Creswell & Creswell, 2018). While changing the instrumentation helps to minimize the threats of cross-contamination of groups and testing, it in itself poses a threat by impacting the scores on the outcome. To minimize this threat, the order of the questions changed, but the questions remained the same.

External validity threats. One threat to validity is the interaction of selection and treatment. Because the participants in this experiment are primarily Black and Latino, study results cannot be generalized to individuals who do not have the same ethnic background as the participants in the study. While restricting claims about ethnic groups to which the results cannot be generalized, I can extend claims to students with similar academic levels as those in the study. Interaction of setting and treatment poses a threat to validity. The setting of participants in the study was urban areas with similar median incomes. To minimize this threat, the experiment was conducted in various locations that include New York and Connecticut. Lastly, the results of this experiment are time-bound, preventing the ability to generalize the results to past or future situations. To minimize this threat, participants received questions that test the same standards as those tested during the June Regents exam.

While measures were taken to minimize external threats to validity, generalizations could not be made based on statistical procedures but could potentially be made to similar populations. This study was the first step in understanding the impact of MathConceptz. The MathConceptz program would have to be built out to an entire Algebra course before making generalizations based on statistics.

Data Analysis

Data analysis consisted of three steps that involved organizing and cleaning the data, running descriptive statistics, and identifying the relationship between various independent and dependent variables.

First, I organized and cleaned the data. I created a database that organized the 79 students in the study according to their group number and teacher. In the database, I numbered the students from 1 - 79. I separated the students by school. For example, students 1- 15 were from school A. I took the first 15 students in the database from school A and had their names next to their matching identification number, demographic data (race, gender, free/reduced lunch), instruction type (control, blended, intervention), and teacher quality rating.

I then ran descriptive statistics to describe the sample by gender, race, and free/reduced lunch to ensure that all groups were similar. I then ran the descriptors against the pre- and post-test scores to determine if there was a change in pre-and post-test scores for each descriptor in relation to the hypotheses. For hypothesis 1, I tested whether there was a correlation between students' pre- and post-test scores in the face-to-face and blended learning groups, and students' gender, race, and whether they receive free/reduced lunch. For hypothesis 2, I tested whether there was a correlation between students' pre- and post-test scores in the face-to-face and MathConceptz groups, and students' gender, race, and whether they receive free/reduced lunch. For hypothesis 3, I tested whether there was a correlation between students' pre- and post-test scores in the MathConceptz and blended learning groups, and students' gender, race, and whether they receive free/reduced lunch.

Second, I used the IO Education software to grade the pre- and post-tests. I uploaded the test items and correct responses to the software. I then scanned student scantrons through the software. After scanning, the software automatically uploaded student responses into an Excel spreadsheet. The software identifies correct and incorrect responses as measured by the pre-populated responses. Students received two scores representing the number of questions solved correctly on the pre- and post-tests. Exam scores ranged from 0 to 15. I then added the pre- and post-test scores to the database next to each students' identification number. I organized the remaining students in the same manner by school.

Third, I identified the relationship between various independent and dependent variables to determine the most significant factor affecting changes in students' scores from pre- to post-test. I performed a repeated-measures analysis of variance (ANOVA) with test score as the dependent variable and factors for group and school as the independent variables. First, an ANOVA was conducted with Test (pre vs. post) as a repeated factor and Group (Instruction vs. Instruction and MathConceptz, vs. MathConceptz only) as a between-subjects factor to test for two main effects and an interaction, and their implications for the three hypotheses. Second, an ANOVA was conducted with Test (pre, post) as a repeated factor and Teacher Quality (ineffective, developing, effective, highly effective) as a between-subjects factor. In addition, an ANOVA was conducted with Test (pre, post) as a repeated factor) and School (A, B, C, D, E) as a between-subjects factor. Significance levels were indicated to determine the impact of each intervention model on pre- and post-test scores depending on group, teacher, school, and student demographics. Lastly, I conducted additional ANOVA testing to determine the differences in the dependent variable (pre-test), based on the factors (treatment, gender, ethnicity, and free or reduced-cost lunch eligibility) to test for group equivalence after randomization. Significance levels were indicated to determine the impact of each factor on students’ pre-test scores.

Following ANOVA testing, I conducted an analysis of covariance (ANCOVA) to test for program effects and interactions between the dependent variable (post-test) and factors (treatment, teacher, gender, ethnicity, and free/reduced-price lunch eligibility), with (post-test) as a covariate. Significance levels were indicated to determine the impact of each two-way interaction (treatment and gender, treatment and ethnicity, and treatment and free/reduced-cost lunch) on students’ post-test scores, with teacher as a factor. A repeated ANCOVA was performed, removing teacher as a factor and adding teacher rating as a covariate. Further analysis was conducted to determine the impact of treatment on post-test scores. Post-hoc tests were performed to reveal which treatments (face-to-face, blended, intervention) significantly differed from each other. Significance levels were indicated to determine the impact of treatment on the differences in students pre- to post-test scores.

In the next chapter, the findings from these analyses are discussed.

CHAPTER 4: FINDINGS

The purpose of this study was to compare the impact of face-to-face and MathConceptz instruction on student performance in one unit of Algebra, as measured by student pre- and post-test scores. The MathConceptz approach was a treatment for student instruction to measure whether there is a significant increase in student performance between pre- and post-test scores. The expectation that MathConceptz results in a statistically significant increase in student performance was reflected in the tested hypotheses. Chapter 4 is organized as follows: First, I present descriptive statistics for the variables of interest. Then, I present the results of mixed ANOVA analyses that were conducted to address the research questions previously stated; to determine the extent to which instruction type (face-to-face instruction, blended learning, and MathConceptz online instruction) improved test scores after one of the three instruction types was implemented. Lastly, I will summarize the findings.

Descriptive Statistics

Before conducting analyses to test the hypotheses, descriptive statistics were obtained for sample characteristics: instruction type, school, ethnicity, gender, free or reduced lunch eligibility, and participant groupings. As can be seen in Table 4a, in terms of the study sample composition, participants were roughly equally divided between the three different conditions; Control (32.9%); Blended (34.2%); and the MathConceptz only condition (32.9%). Participants were also roughly equally split by gender; males made up 49.4% of the sample, and females made up 50.6% of the sample. The ethnicity of participants did not include any White students, only Black (74.7%) and Hispanic (25.3%) participants. Additional sample composition information can be found in Table 4a.

Table 4a

Sample Characteristics and Groupings of Participants

Variable	Distribution (in percentages)
Instruction Type	Control (32.9%); Blended (34.2%); Intervention (32.9%)
School	School1 (24.1%); School2 (29.1%); School3 (34.2%); School4 (12.7%)
Ethnicity	Black (74.7%); Hispanic (25.3%)
Gender	Male (49.4%); Female (50.6%)
Free or Reduced Lunch	Yes (92.4%); No (7.6%)
Percentage of Students Under Teacher	TeacherA (21.5%); TeacherB (29.1%); TeacherC (12.7%); TeacherD (24.1%); TeacherE (12.7%)

Note: N=79.

Descriptive statistics were also obtained for measures of central tendency and variance for variables of interest: pre- and post- test scores, the difference between pre- and post- test scores, and teacher ratings. The mean, standard deviation, range, skewness, and kurtosis, is provided for these variables in Table 4b. These findings support there being a difference in performance between the pre-test and post-test period. There was a mean difference of .120 between the pre-test and post-test (*SD*=.195). The mean score for the post-test was 54.55% greater than the pre-test, indicating that there was an improvement in student performance; however, testing was necessary to determine the significance of the improvement. In addition, descriptive statistics obtained showed teacher ratings along the Danielson scale (1.00 = ineffective, 2.00 = developing, 3.00 = effective, 4.00 = highly effective). As seen in Table 4, the average teacher rating in components 3b, 3c, and 3d were developing for the five teachers in the study. Skewness and kurtosis did not support there being a non-normal distribution of the data.

Table 4b

Measures of Central Tendency and Variance for the Entire Sample

	M	*SD*	RANGE	MIN	MAX	SKEW	KURTOSIS
Pre-Test	.222	.151	.580	.000	.580	.470	-.345
Post-Test	.343	.189	.750	.000	.750	.148	-.558
Difference (Post-Pre)	.120	.195	.910	-.330	.580	.105	-.274
Teacher Rating 3b	2.000	.000	.000	2.000	2.000	---	---
Teacher Rating 3c	2.076	.712	2.000	1.000	3.000	-.111	-.988
Teacher Rating 3d	2.127	.335	1.000	2.000	3.000	2.290	3.327

Analyses for Hypothesis Testing

To test the extent to which instruction type (face-to-face instruction, blended learning, and MathConceptz online instruction) improved test scores, I conducted a mixed ANOVA with the testing period (pre vs. post) as a within-subject variable, instruction type as a between-subject variable, and test score as the outcome measure. I also ran several post-hoc tests to examine possible differences between specific groups. The mixed ANOVA revealed one significant main effect of testing period, $F(1, 76) = 34.1$, $p < .001$, with pre-intervention test scores being on average lower than the post-intervention test scores, ($M = 0.22$, $SD = 0.15$ vs. $M = 0.34$, $SD = 0.19$, respectively). There was also a significant interaction between testing period (pre vs. post) and instruction type (Control, Blended, and MathConceptz only), $F(1, 76) = 7.57$, $p < .001$. Based on these findings, both testing period and instruction type had a significant impact on student performance where students in the post-test period who received MathConceptz education were the most successful.

To unpack the interaction, I ran pairwise comparisons between pre- and post-test scores for each of the three instruction types, using Bonferroni adjustment. The results of the pairwise comparisons can be found in Table 5a. The pairwise comparisons revealed that students in the blended instruction group scored higher than the control group on the post-test, $p = .01$ ($M = 0.41$, $SD = 0.19$ vs. $M = 0.27$, $SD = 0.17$, respectively). Thus, the null hypothesis for hypotheses one, that students in the blended learning group will not outscore the face-to-face instruction group on the post-test controlling for the pre-test, is not supported as students in the blended instruction group outscored the face-to-face instruction group after the intervention. However, there was no significant difference between the MathConceptz group and the face-to-face instruction group ($p = .10$), or between the MathConceptz group and the blended instruction group ($p = .22$). Thus, the hypotheses that students in the MathConceptz group will not outscore the face-to-face instruction group, controlling for the pre-test, is not supported. Likewise, the hypotheses that students in the MathConceptz group will not outscore the blended learning group, controlling for the pre-test, is also not supported.

Table 5a

Pairwise Comparisons Between Instruction Type and Test Period

Test Period	Group 1	Group 2	n1	n2	Adjusted p-value
Pre-Test	Face-to-face	Blended	26	27	0.72
Pre-Test	Face-to-face	MathConceptz	26	26	1
Pre-Test	Blended	MathConceptz	27	26	1
Post-Test	Face-to-face	Blended	26	27	0.01*
Post-Test	Face-to-face	MathConceptz	26	26	0.3
Post-Test	Blended	MathConceptz	27	26	0.67

Note. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ‘ ’ 1

As can be seen in Table 5b, and consistent with the main effect of the testing period (pre- vs. post), the results show that scores for all instruction types improved after the intervention. There were improvements across the board both on average and on highest attained test scores. The largest improvement was seen for the blended instruction group, where student performance mean scores increased from 20% to 41%; however, the blended instruction group also had the greatest range of performance in the pre- and post-test periods (83%) and standard deviation (21%). Therefore, while students performed better, not all students benefited. After the intervention, there was only a significant difference between the blended instruction and control group, with the former being higher than the latter. The full information for pre- and post-test scores across conditions can be found in Table 5b.

Table 5b

Descriptive Statistics for Pre/Post-Tests and Post/Pre-Test Differences Across Conditions

Test Period	Instruction Type	*M*	*SD*	MIN	MAX	RANGE	IQR
Pre-Test	Blended	20%	15%	0%	58%	58%	25%
	Control	25%	14%	0%	50%	50%	16%
	Intervention	22%	16%	0%	58%	58%	25%
Post-Test	Blended	41%	19%	0%	75%	75%	25%
	Control	27%	17%	0%	67%	67%	27%
	Intervention	35%	18%	0%	67%	67%	25%
Difference (Post-Pre)	Blended	21%	21%	-25%	58%	83%	25%
	Control	2%	18%	-33%	33%	66%	25%
	Intervention	13%	15%	-17%	33%	50%	25%

Pre- and Post-Test Scores Across Teachers, Ethnicities, Gender, and SES

Pre- and Post-test Scores Across Teachers. Analyses were also conducted to examine differences in pre- and post-test scores across different teachers to determine if teachers had an impact on the findings. Analyses were conducted only on Groups 1 and 2, as Group 3 interacted with MathConceptz, solely. As can be seen in Table 6, the largest improvements in test scores across conditions were seen with teachers B and D. Teacher B's scores increased from 27% to 41%. Teacher D's scores increased from 16% to 35%. Teacher C began and ended with lower scores between the different testing periods, but still saw an improvement in scores (from 12% to 22%). Conversely, Teacher E began and ended with the highest scores (36% and 44%, respectively).

Table 6

Pre- and Post-test Scores Across Different Teachers

Test Period	Teacher	M	SD	MIN	MAX	RANGE	IQR
Pre-Test	A	19%	18%	0%	50%	50%	33%
	B	27%	12%	8%	50%	42%	23%
	C	12%	9%	0%	25%	25%	13%
	D	16%	9%	0%	33%	33%	17%
	E	36%	17%	17%	58%	41%	33%
Post-Test	A	23%	17%	0%	50%	50%	25%
	B	41%	16%	8%	75%	67%	15%

	C	22%	11%	8%	42%	34%	15%
	D	35%	20%	8%	75%	67%	33%
	E	44%	23%	8%	67%	59%	50%
Difference (Pre-Post)	A	4%	24%	-25%	50%	75%	42%
	B	14%	22%	-33%	50%	83%	31%
	C	10%	13%	-8%	33%	10%	10%
	D	19%	25%	-8%	58%	66%	46%
	E	8%	13%	-8%	25%	33%	25%

Pre- and Post-test Scores Among Black and Hispanic Students. As can be seen in Table 7, pre- and post-test scores of Hispanic and Black students revealed that test scores were comparable across both groups before and after instruction, though Hispanic students did show a greater improvement as they had lower initial scores. As seen in Table 7, Hispanic students had lower pre-test scores (*M* =.200) than Black students (*M* =.230). Conversely Hispanic students had higher post test scores (*M* =.363) than Black students (*M* =.336), showing that Hispanic students showed greater improvement as a result of the intervention.

Table 7

Pre- and Post-test Scores Across Blacks and Hispanic Students

Test Period	Ethnicity	M	SD	MIN	MAX	RANGE	IQR
Pre-Test	Black	.230	.149	.000	.580	.580	.250
	Hispanic	.200	.159	.000	.500	.500	.250
Post-Test	Black	.336	.182	.000	.750	.750	.250
	Hispanic	.363	.213	.000	.670	.670	.310
Difference (Post-Pre)	Black	.106	.210	-.330	.580	.910	.330
	Hispanic	.162	.139	-.170	.330	.500	.170

As can be seen in Table 8, both males and females had similar scores after instruction (*M* =.340 and .346, respectively). However male students showed a slightly higher improvement as they had lower scores prior to instruction (*M* =.209) than female students (*M* =.236). The information for pre- and post-test scores across male and female students can be found in Table 8.

Table 8

Pre- and Post-test Scores Across Male and Female Students

Test Period	Sex	M	SD	MIN	MAX	RANGE	IQR
Pre-Test	Female	.236	.150	.000	.580	.580	.140
	Male	.209	.152	.000	.500	.500	.250
Post-Test	Female	.346	.210	.000	.750	.750	.330

	Male	.340	.168	.000	.670	.670	.170
Difference (Post-Pre)	Female	.111	.202	-.330	.580	.910	.310
	Male	.130	.190	-.250	.580	.830	.330

Free or reduced-cost lunch status of students (a proxy for SES in this research) also impacted differences in pre- and post- test scores. Students who received free or reduced-cost lunches had lower pre-test scores (*M* = .214) than students who did not (*M* = .320). Though students receiving free or reduced-cost lunches had lower pre-test scores, they reflected greater improvement on test scores after instruction with a mean difference of .127 and .043, respectively. The information for pre- and post- test scores across students who are (vs. are not) receiving free or reduced-cost lunches can be found in Table 9.

Table 9

Pre- and Post-test Scores of Students Receiving vs. Not Receiving Free or Reduced-cost Lunch

Test Period	Free or Reduced Lunch	M	SD	MIN	MAX	RANGE	IQR
Pre-Test	No	.320	.176	.170	.580	.410	.350
	Yes	.214	.147	.000	.580	.580	.250
Post-Test	No	.362	.170	.170	.580	.410	.350
	Yes	.342	.192	.000	.750	.750	.290
Difference (Post-Pre)	No	.043	.136	-.080	.250	.330	.270
	Yes	.127	.198	-.330	.580	.910	.250

The results from several ANOVA tests performed, to determine the differences in pre-test scores based on several factors, are included in Table 10. The factors included in the ANOVA tests were treatment, gender, ethnicity, and free or reduced-cost lunch eligibility. The findings of these tests would determine whether these factors influenced participants' pre-test scores. As seen in Table 10, the ANOVA tests show there was an insignificant difference in pre-test scores when based on the various factors. Different treatment (p=.497), gender (p=.446), ethnicity (p=.442), and free or reduced-cost lunch eligibility (p=.102) group categories each failed to achieve a significance of $p < .05$. The different categories of these variables are not supported as factors impacting pre-test scores, showing group equivalence after randomization.

Table 10

ANOVA Tests for Differences in Pre-test Scores

	Sum of Squares	Df	Mean Square	F	Sig.
ANOVA Test for Difference of Pre-Test Scores Based on Treatment Groups					
Between Groups	0.032	2	0.016	0.705	0.497
Within Groups	1.742	76	0.023		
Total	1.774	78			
ANOVA Test for Difference of Pre-Test Scores Based on Gender Groups					
Between Groups	0.013	1	0.013	0.587	0.446

Within Groups	1.761	77	0.023		
Total	1.774	78			
ANOVA Test for Difference of Pre-Test Scores Based on Ethnicity Groups					
Between Groups	0.014	1	0.014	0.598	0.442
Within Groups	1.76	77	0.023		
Total	1.774	78			
ANOVA Test for Difference of Pre-Test Scores Based on Free Reduced Lunch Groups					
Between Groups	0.061	1	0.061	2.742	0.102
Within Groups	1.713	77	0.022		
Total	1.774	78			

ANCOVA tests were performed to test for program effects and two-way interactions between treatment and gender, treatment and ethnicity, and treatment and free/reduced-cost lunch. Table 11 shows the results of the ANCOVA models with teacher as a factor. ANCOVA testing on the difference of post-test scores showed significance in the two-way interaction between treatment and ethnicity, with teacher as a factor. This model suggests that when considering teacher as a factor, treatment and students' ethnicity may impact students' post-test scores.

Table 11

ANCOVA Test for Difference in Post-Test Scores

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	2.154[a]	50	.043	1.932	.032
Intercept	.635	1	.635	28.496	.000
PreTest	.007	1	.007	.305	.585
Treatment	.074	2	.037	1.659	.208
Teacher	.328	4	.082	3.680	.016
Gender	.001	1	.001	.032	.859
Ethnicity	.033	1	.033	1.468	.236
Free Reduced Lunch	.027	1	.027	1.209	.281
Treatment*Teacher	.090	7	.013	.575	.770
Treatment*Gender	.116	2	.058	2.609	.091
Treatment*Ethnicity	.194	2	.097	4.350	.023
Treatment*FreeReducedLunch	.001	1	.001	.040	.844
Error	.624	28	.022		
Total	12.059	79			
Corrected Total	2.778	78			

a. R Squared = .775 (Adjusted R Squared = .374)

A repeated ANCOVA test was performed to test for program effects and two-way interactions between treatment and gender, treatment and ethnicity, and treatment and free/reduced-cost lunch. Table 12 shows the results of this model, which included teacher as a removed factor and teacher rating as an added covariate. The repeated ANCOVA testing on the difference of post-test scores also showed significance in the two-way interaction between treatment and ethnicity. This model suggests that treatment and students' ethnicity may impact students' post-test scores.

Table 12

ANCOVA Test for Difference in Post-Test Scores

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.371[a]	18	.076	3.248	.000
Intercept	0.000	0			
PreTest	.112	1	.112	4.760	.033
TeacherRating3b	0.000	0			
TeacherRating3c	.158	1	.158	6.726	.012
TeacherRating3d	.065	1	.065	2.756	.102
Treatment	.151	2	.075	3.218	.047
Gender	.001	1	.001	.036	.851
Ethnicity	.034	1	.034	1.469	.230
FreeReducedLunch	.003	1	.003	.128	.721
Treatment*Gender	.030	2	.015	.649	.526
Treatment*Ethnicity	.168	2	.084	3.584	.034
Treatment*FreeReduced Lunch	.000	1	.000	.014	.907
Error	1.407	60	.023		
Total	12.059	79			
Corrected Total	2.778	78			

a. R Squared = .494 (Adjusted R Squared = .342)

The results of the ANCOVA models included findings which supported further examination to understand the significance of the factors treatment and teacher, and the interaction between treatment and ethnicity. These factors and interaction were each found to be significant in one of the ANCOVA models. Based on this finding, post-hoc testing, using the Bonferroni method, was performed to further examine statistical significance where the familywise error rate is controlled. Based on Table 13, the comparison of teachers resulted in a lack of statistical significance, suggesting that teachers did not have a significant influence on students' post-test scores.

Table 13

Bonferroni Post Hoc Test - Teacher

(I) Teacher		Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c] Lower Bound	Upper Bound
Teacher A	Teacher B	-.157[a,b]	.055	.080	-.324	.010
	Teacher C	.030[a,b]	.064	1.000	-.163	.224
	Teacher D	-.061[a,b]	.054	1.000	-.227	.104
	Teacher E	-.213[a,b]	.079	.111	-.453	.026
Teacher B	Teacher A	.157[a,b]	.055	.080	-.010	.324
	Teacher C	.187[a,b]	.068	.100	-.019	.394
	Teacher D	.096[a,b]	.055	.916	-.071	.262
	Teacher E	-.057[a,b]	.068	1.000	-.263	.150
Teacher C	Teacher A	-.030[a,b]	.064	1.000	-.224	.163
	Teacher B	-.187[a,b]	.068	.100	-.394	.019

	Teacher D	-.092[a,b]	.064	1.000	-.286	.102
	Teacher E	-.244[a,b]	.093	.144	-.529	.041
Teacher D	Teacher A	.061[a,b]	.054	1.000	-.104	.227
	Teacher B	-.096[a,b]	.055	.916	-.262	.071
	Teacher C	.092[a,b]	.064	1.000	-.102	.286
	Teacher E	-.152[a,b]	.078	.612	-.390	.086
Teacher E	Teacher A	.213[a,b]	.079	.111	-.026	.453
	Teacher B	.057[a,b]	.068	1.000	-.150	.263
	Teacher C	.244[a,b]	.093	.144	-.041	.529
	Teacher D	.152[a,b]	.078	.612	-.086	.390

Based on estimated marginal means
a. An estimate of the modified population marginal mean (I).
b. An estimate of the modified population marginal mean (J).
c. Adjustment for multiple comparisons: Bonferroni.

Table 14 includes findings on further analysis of the impact of treatment on post-test scores. Post-hoc tests were performed to reveal which treatments (face-to-face, blended, intervention) significantly differed from each other. Similar to the results from ANOVA testing, post-hoc testing confirmed that the only significant comparison is that between the blended instruction and face-to-face instruction groups (p=.012). More specifically, in the blended instruction group there was a significant improvement from student pre- to post-test scores when compared to the face-to-face instruction group.

Table 14

Bonferroni Post Hoc Test - Treatment

(I) Group		Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d] Lower Bound	Upper Bound
Control	Blended	-.144[*,b,c]	.046	.012	-.261	-.027
	Intervention	-.099[b,c]	.046	.119	-.216	.018
Blended	Control	.144[*,b,c]	.046	.012	.027	.261
	Intervention	.045[b,c]	.046	1.000	-.074	.163
Intervention	Control	.099[b,c]	.046	.119	-.018	.216
	Blended	-.045[b,c]	.046	1.000	-.163	.074

Based on estimated marginal means
*. The mean difference is significant at the .05 level.
b. An estimate of the modified population marginal mean (I).
c. An estimate of the modified population marginal mean (J).
d. Adjustment for multiple comparisons: Bonferroni.

The results of post-hoc tests analyzing the interaction between treatment and ethnicity are found in table 15. Post-hoc tests were performed to determine what the significant interactions were between treatment and ethnicity. The confidence levels for each comparison between treatment and ethnicity are evidence of significant interaction between treatment and Black students, and treatment and Hispanic students.

Table 15

*Bonferroni Post Hoc Test - Treatment*Ethnicity Interaction*

Ethnicity		Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Black	Control	.197[a,b]	.038	.119	.275

	Blended	.436[a,b]	.038	.358	.515
	Intervention	.332[a,b]	.037	.255	.409
Hispanic	Control	.352[a,b]	.058	.233	.472
	Blended	.321[a,b]	.060	.197	.444
	Intervention	.384[a,b]	.067	.247	.521

a. Covariates appearing in the model are evaluated at the following values: Pre-Test = .222476.

b. Based on modified population marginal mean.

Summary

In summary, a mixed ANOVA revealed that pre-intervention test scores were on average lower than the post-intervention test scores. That is, all students scored, on average, higher on the test after any intervention than before an intervention. There was also a significant interaction between the testing period (pre vs. post) and instruction type. To unpack the interaction, I ran pairwise comparisons between pre- and post-test scores for each of the three groups. These tests revealed that the interaction between the testing period (pre vs. post) and instruction type was driven by a significant difference in test scores between the control group (i.e., face-to-face instruction) and the blended instruction group. Specifically, students in the blended instruction group scored higher than the control group on the post-test. There were no significant differences between the face-to-face instruction and MathConceptz groups. Supplementary analyses revealed that augmented instruction types had a greater impact on male (vs. female) students, Hispanic (vs. Black) students and students who are (vs. are not) receiving free or reduced-cost lunches.

Additional ANCOVA testing revealed that there was significant interaction between treatment and ethnicity, prompting further post-hoc analysis to further understand the significance of comparisons between sets of teachers, treatments, and interaction between treatment and ethnicity. Post-hoc tests confirmed the finding that there was a significant difference in test scores between the control and blended instruction groups. In addition, post-hoc analysis found significant interaction between treatment and Black and Hispanic students. The implications of these findings are discussed in the next chapter.

CHAPTER 5: SUMMARY AND DISCUSSION

Historically, Black and Hispanic students in urban schools have tended to perform disproportionately lower in mathematics than their Caucasian counterparts in suburban settings. Research suggests the difference in performance is primarily due to the math instruction received in urban schools, which is characterized by procedural practices, such as drill and skill and rote memorization, as well as the structures of classrooms, schools, and districts (Becker & Luthar, 2002; Flores, 2007). Research also suggests that the poor math instruction in urban schools may also be a result of poor teacher quality. Intelligent tutoring systems (ITS) have become a strategy of providing students with supplemental instruction in math. However, while research on ITS' has shown that ITS' generally increase student performance in math, ITS' tend to provide math support focused on procedures as opposed to concepts (Dynarski et al., 2007). The focus on procedures may be problematic as research suggests that a deep understanding of math requires math fluency and a conceptual understanding of math (Llewellyn, 2012; Rittle-Johnson & Schneider, 2014; Kent & Foster, 2015).

This experimental study aimed to test the impact of an intelligent tutoring system (ITS), MathConceptz, on students' performance in Algebra, as measured by pre- and post-test scores. Unlike the current ITS' for mathematics, MathConceptz includes lessons focused on building students' conceptual understanding of Algebra. This chapter discusses the major findings of this study as related to the literature on Algebra performance of Black and Hispanic students in urban schools, and the impact of ITS' on the Algebra performance of this group of students. This chapter also includes a discussion of the limitations of the study, as well as areas for future research and the implications for teaching math conceptually. To provide a context for a discussion on the findings, I begin with a brief overview of the design of the study.

The Research Study

Academic preparation in math requires a focus on building mathematical competence, which is characterized by conceptual understanding as well as procedural fluency (Llewellyn, 2012; Rittle-Johnson & Schneider, 2014; Kent & Foster, 2015). However, instruction in urban schools is primarily focused on procedural fluency, and is based on drill and kill and rote memorization. The lack of focus in urban schools on building students' conceptual knowledge prevents students from gaining mathematical competence in math, which is necessary to achieve academic success in math. Similar to instruction in urban schools, ITS' in mathematics, which are currently used as a supplement to instruction, emphasize instruction in procedural fluency as opposed to building students' conceptual understanding of math. Yet, they have the potential to also focus on math concepts to help build students' mathematical competence, and thus improve their academic outcomes in math.

In response to the tendency of ITS' to focus on procedures, MathConceptz aims to build students' conceptual understanding of math while including other aspects of ITS' such as practice problems and student feedback. In order to determine the impact of MathConceptz on student performance in Algebra, I conducted an experimental study. A population of 79 students across 4 schools ($n = 79$) were divided into three instructional groups within each school to receive solely face-to-face Algebra instruction (Group 1), Algebra instruction solely from MathConceptz (Group 3), or both face-to-face Algebra instruction and Algebra instruction from MathConceptz (Group 2). Prior to the intervention, students completed a ten-question pre-test on the Algebra topics of solving linear and quadratic equations, and factoring. In their three groups within each school, students then received eight days of instruction on the topics tested in the pre-test. Following the intervention students completed a post-test similar to the pre-test. I hypothesized that students in the MathConceptz group would outperform students in the face-to-face and blended instruction groups.

Initial analysis began by entering the pre-and post-test scores, teacher ratings, and student descriptive variables in an Excel program and cleaning the data. Analyses were then conducted to obtain descriptive statistics and measures of central tendency for variables of interest: pre- and post-test scores, teacher ratings, and student demographics. Lastly, I conducted mixed ANOVA analyses to address the research question to determine the extent to which instruction type (face-to-face instruction, blended learning, and MathConceptz online instruction) improves test scores after one of the three instruction types is implemented. In my analysis I then examined the relationship between students' ethnicity and test performance, students' gender and test performance, students' socioeconomic status (SES) and test performance, and teacher quality and test performance, and identified the impact that MathConceptz has on student performance when measured against each variable. I now turn to a discussion of the major findings of this study.

Findings

The findings from this study echo the current research on ITS', whereby the use of ITS' as a supplement to instruction has been found to have a positive impact on student performance (Melis & Siekmann, 2004; Razzaq, Feng, Nuzzo-Jones, Heffernan, Koedinger, Junker, Ritter, Knight, Mercado, Turner, Upalekar, Walonoski, Macasek, Aniszczyk, Choksey, Livak, & Rasmussen, 2005; Beal et al., 2010; Pane et al., 2013). On average, students showed an improvement pre- and post-intervention, mirroring the research suggesting that underperforming schools are more likely to see an improvement in student math performance as a result of ITS' such as MathConceptz (Cascaval, Fogler, Abrams, Durham, 2007). However, the study showed that students in the blended instruction group showed significantly more growth than the students in the face-to-face instruction group. Taking into consideration individual factors such as teacher quality and students' gender, ethnicity, and SES, the results of the study showed that low-income, male Hispanic students with lower performing teachers are more likely to benefit from ITS' such as MathConceptz. The discussion below focuses on the impact of MathConceptz on students' performance when considering these factors.

The impact of ITS' on student math performance. The research base suggests that ITS programs designed to support exploratory learning while improving students' basic computational skills have yielded significant student improvement in math (Melis & Siekmann, 2004; Razzaq, Feng, Nuzzo-Jones, Heffernan, Koedinger, Junker, Ritter, Knight, Mercado, Turner, Upalekar, Walonoski, Macasek, Aniszczyk, Choksey, Livak, & Rasmussen, 2005; Beal et al., 2010; Pane et al., 2013). Several studies that use ITS' as a supplement to face-to-face instruction have compared student performance on math pre- and post-tests as a result of using ITS'(Clark & Whitestone, 2014). These studies, which test the impact of ITS programs such as PUMP, The Cognitive Tutor, and Animal Watch, generally suggest that ITS' improve student performance in mathematical processes, higher order thinking, and problem solving skills as measured by pre- and post-test scores (Corbett et al., 1997; Razzaq et al., 2005; Beal et al., 2010; Clark & Whitestone, 2014).

Echoing these findings, this study found that students who received blended learning instruction (i.e. used MathConceptz as a supplement to face-to-face instruction) showed significant growth between pre- and post-test scores when compared to students in the face-to-face instruction groups. One reason for this finding might be that MathConceptz' program design incorporates components that research suggests are necessary for an ITS to be effective. For example, research suggests that effective ITS' are aligned to the Common Core standards and include multimedia, interactivity, and student feedback to improve student performance (Dynarski et al. (2007; Beal et al., 2010; Clarke & Whitestone, 2014). These components are incorporated in MathConceptz' design. Though the study did not test these components, it is possible that as a result of including these components, student performance improved when MathConceptz was used as a supplement to instruction.

The findings from the study also align to the research suggesting that math competence depends on the development of both procedural fluency and conceptual understanding (Llewellyn, 2012; Rittle-Johnson & Schneider, 2014; Kent & Foster, 2015). MathConceptz includes a focus on building students' conceptual understanding and using that conceptual understanding to build their procedural fluency. In the blended learning group, it is a possibility that students were exposed to both procedural fluency and concept-building during the face-to-face instruction and from the program. It is also possible that MathConceptz acted as a supplement to face-to-face instruction, likely contributing to the significant increase from pre- to post-test scores.

The impact of ITS' when considering teaching quality. Urban schools tend to employ less qualified teachers than suburban schools (Jacob, 2007; McKinney et al., 2007; Murnane & Steele, 2007; Adnot et al., 2017; Feng & Sass, 2018), which leads to poor instructional quality in math and, ultimately, students' inability to engage in concept-based instruction. Because of the conventional instructional approach most utilized by teachers in urban settings, the majority of students in urban schools find it challenging to understand or apply conceptual math in a real world context. Online learning has been identified as one possible solution to the problem of teacher quality in K-12 mathematics education (Smith et al., 2005; Cascaval et al., 2007). Schools have begun to shift from traditional education to online learning because it enables learning to take place under the learner's control. In addition, because online learning provides access to education regardless of a learner's location, it may be a promising method of promoting equity in instructional opportunities (Dichev, Dicheva, Agre, and Angelova, 2013).

Descriptive statistics from the study findings showed that the teachers in the study had an average teacher quality rating of “developing.” Specifically, the average teacher rating for Danielson components 3b (Questioning and Discussion), 3c (Student Engagement), and 3d (Assessment in Instruction) was developing. These ratings of teacher quality mirror the research that students in urban settings tend to have teachers that may utilize less effective instructional practices, leading to their lack of preparation for STEM fields. Results of the study found that while both groups that received instruction from MathConceptz experienced higher growth between pre- and post-tests than the face-to-face instruction group, students in the blended instruction group showed a significant difference in performance, when considering teacher quality. Because the study results showed a significant difference between the test scores of the blended instruction and face-to-face instruction groups, but not between the MathConceptz and blended instruction groups, it can only be concluded that an ITS such as MathConceptz should be used as a supplement to teacher instruction, not necessarily as a replacement.

The impact of ITS' when considering student demographics. The research suggests that Blacks and Hispanics are underrepresented in STEM fields and, compared to their Whie and suburban counterparts, are less academically prepared for STEM fields. In 2010, a report from The National Academies, *Rising Above the Gathering Storm*, *Revisited* found that less than 15% of undergraduate degrees in STEM were earned by Black and Hispanic students (Koledoye et al., 2011). Some possible reasons for the lack of presence of Black and Hispanic students in STEM education and occupations can be attributed to limited access to higher level mathematics courses, and limited academic preparation in mathematics, stemming from poor teacher quality and instruction heavily emphasized by math procedures as opposed to concepts (Koledoye et al., 2011; MacPhee et al., 2013). In the study, Black and Hispanic students showed an average higher growth percentage in the MathConceptz intervention groups than the face-to-face instruction groups. Specifically, the average growth percentage was significantly higher in the blended instruction group than the face-to-face instruction group when considering student ethnicity. These results suggest that Black and Hispanic students may possibly benefit from an ITS like MathConceptz. Not only are Black and Hispanic students underrepresented in STEM fields, but this representation is even less for Black and Hispanic students from disadvantaged backgrounds. Similarly, the findings from the study suggest that for low-income students in urban settings, for as much as free or reduced lunch can predict SES, ITS' such as MathConceptz can improve student performance being that students in the study that receive free or reduced lunch showed the most growth between pre- and post-test scores.

Though this was a small study that tested student knowledge of one unit of Algebra, this is the only study that measures the impact of an ITS on student performance when comparing face-to-face instruction to blended instruction. This finding is particularly significant for Black and Hispanic students in urban settings where some researchers have argued that students in urban schools are not frequently exposed to “good” mathematics teaching and do not have equitable access to good mathematics instruction (Gutierrez, 2000; Battey, 2013), because it explores alternative methods of teaching Algebra. For example, as the students in the blended instruction group showed significantly more improvement than students in the face-to-face instruction group, this study adds to the literature on using ITS’ as a form of supplemental instruction in the classroom. Because students in the blended group outperformed students receiving face-to-face instruction, this study suggests there is a possibility that a program like MathConceptz may help to alleviate the problem of poor instruction in urban schools.

Implications for Practice

The findings for this study suggest several implications for those who teach mathematics in urban settings with predominantly Black or Hispanic students, and use ITS’ to supplement instruction. The findings also have implications for my own practice as a coach and for those who are engaged in professional development with teachers.

First, although the study was conducted in urban schools with a predominantly Black and Hispanic population, the design of the program lends itself not only to teachers of low-income Black and Hispanic students, but to teachers in general. MathConceptz is designed into short lessons that first teach a math topic conceptually, then connects the concept to the mathematics algorithm to build students mathematical competence. Because of its focus on conceptual understanding schools should consider using an ITS such as MathConceptz as a supplement to instruction. Students can use a program such as MathConceptz in the classroom as a form of differentiated instruction, during tutoring, or at home. This will allow students to reinforce their learning in the classroom and receive additional exposure to, and practice with, mathematics topics they are learning from their teacher. This will also allow students to build their conceptual understanding of mathematics and may, possibly, result in higher test scores.

Second, the findings of the study showed that students in both the MathConceptz and blended instruction groups had a higher average growth in test scores than the face-to-face instruction group, with the blended instruction group showing a significant difference. Because MathConceptz focuses on instructing students in a way that builds their conceptual understanding of math, teachers of low-income Black and Hispanic students should consider using a program such as MathConceptz as a resource to inform their instruction. When lesson planning, teachers can use the lessons in MathConceptz as a guide to create their own lessons, which will hopefully lead them to create more quality lessons that build their students' conceptual understanding of math.

As I work as a coach in urban schools this study also has implications for my own practice. MathConceptz will inform the focus of my coaching with teachers. For example, I will focus my coaching on using programs such as MathConceptz as a differentiation tool as well as a guide to build teachers' lesson planning abilities. Through coaching I can build teachers' capacity to use online software in class with students who need supplemental instruction. I will also use the modules to help teachers develop similar lessons that build their students' conceptual understanding of mathematics. This study suggests the importance of incorporating a blended learning model in math instruction, teaching math conceptually, and drawing connections between math concepts and algorithms to build students' math competence. These findings provide a strong basis for coaching teachers around developing concept-based instruction.

Limitations and Future Research

The study was limited to a sample of 79 students across 4 urban schools in New York and Connecticut. While the demographic makeup of the sample size is similar to the larger population of students, it does limit the generalizability of the results. It is suggested that future research be conducted on a nationwide pool of students to provide further insight on the impact of MathConceptz on student performance.

The study was also limited to five teachers in four schools in New York and Connecticut. While this study provides some insight into the impact of MathConceptz on the performance of students with lower performing teachers, it does not give direct insight on the impact of MathConceptz on student performance for students with higher performing teachers. Future research should be conducted to include teachers from a range of backgrounds and in a range of school contexts to provide further insight on the impact of MathConceptz on student performance when considering teacher quality.

The time frame spent on the intervention and the limited design of MathConceptz also limits the ability to generalize the impact of MathConceptz on student performance in general. Currently, MathConceptz only covers eight Algebra lessons. It is suggested that the current MathConceptz program be expanded to cover a full-year Algebra curriculum to show its impact on student performance when covering an Algebra course in its entirety. Despite these limitations, this study adds to the types of ITS' on the market as well as provides insight into the impact of an ITS that teaches math conceptually on student performance. As this study incorporated a blended learning model, it also provides alternative ways for teachers to engage in math instruction by implementing ITS' as a form of supplemental instruction. Lastly, this study is significant because it suggests that it may be possible to use ITS’, not just as a means to increase students’ procedural fluency, but also as a way to teach math conceptually.

Conclusion

As an educator in urban schools, I frequently come face to face with the inequities in our education system and the achievement gap between White and minority students; inequities that are commonly referred to in research on mathematics education in urban schools. Research frequently suggests that low performance levels seen among marginalized populations are due primarily to unequal access to quality mathematics instruction (Gutierrez 2000; Battey, 2013). Perhaps a program like MathConceptz can chip away at these inequities and create some progress toward closing the achievement gap. Though this study was small and experimental, it has opened up possibilities of expanding the program into a full-year Algebra curriculum and hopefully seeing it implemented in more schools. Expanding the presence of MathConceptz may one day provide a greater influence on both mathematical teaching practices and student performance in urban areas beyond the schools who participated in this study.

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Appendix A - Principal Letter

Letter of Invitation to School Principals

Teaching Algebra conceptually has been the focal point of [insert school] math instruction this school year. Teaching Algebra conceptually means building students' ability to recognize and understand the core underlying ideas of a concept, and to apply those ideas to new contexts. As a doctoral candidate completing my dissertation study, I have created a computer-based program that builds students' understanding of topics in Algebra. The purpose of this study is to have students engage with a computer-based program that teaches Algebra conceptually and improve students' math performance as a result of the program.

The study involves a close examination of the impact of a computer-based program on student math performance. I will work with one Algebra teacher and 30 students taking Algebra for a 30-day period. Over the course of 30 days, students will take short pre- and post-tests and engage in classroom and computer-based Algebra lessons. Data collected on test scores will remain confidential as each student will be assigned an identification number. The study involves no intervention on usual classroom activities and should not compromise the quality of instruction.

Upon meeting, I will discuss the design of the study in more detail and outline the benefits of the study. My ultimate goal is to help students gain a deeper understanding of math content and improve their math scores. It is my sincerest hope that we will be able to partner in this goal.

Sincerely,

Madonna Afriyie
Doctoral Candidate
(347) 782-2897
madonna@stemstrategies.org

Appendix B - Student Letter

Information Letter for Students

You have been selected to participate in the MathConceptz program. MathConceptz is an animated and interactive computer program that teaches the same math topics you are learning in your Algebra class. As a participant, you will be able to use this new algebra program that aims to improve your test scores. You will be asked to dedicate 10 days of your time in school for, at most, 30 minutes each day.

The purpose of this program is to teach you math in a new and interactive way. As part of the study we will test your knowledge of Algebra before you use the program and test how much you learned about Algebra after using the program.

Your participation in the study will remain completely confidential and you have the opportunity to remove yourself from the study at any time. I look forward to learning math with you!

Sincerely,

Madonna Afriyie
Doctoral Candidate
(347) 782-2897
madonna@stemstrategies.org

Appendix C - Consent Forms

PARENTAL PERMISSION TO PERMIT CHILD TO TAKE PART IN RESEARCH

TITLE OF STUDY: MathConceptz - Improving Math Performance
Principal Investigator: Madonna Afriyie-Adams, Doctoral Candidate

STUDY SUMMARY: This consent form is part of an informed consent process for a research study and it will provide information that will help you decide whether you want your child to take part in this study. It is your choice for him/her to take part or not. The purpose of the research is to: test the impact of a computer-based math program on student math performance in Algebra. If your child takes part in the research, s/he will be asked to participate in a 10-question math pre- and post-test, and receive 10 minutes of either instruction from a teacher or the MathConceptz program. Their time in the study will take 10 days for 10 to 30 minutes each day. There are no foreseeable risks in taking part in the study. Possible benefits of taking part may be additional math support and improved math performance. Your child's alternative to taking part in the research study is not to take part in it.

The information in this consent form will provide more details about the research study and what will be asked of your child if you permit him/her to take part. If you have any questions now or during the study, you should feel free to ask them and should expect to be given answers you completely understand. After all of your questions have been answered and you wish your child to take part in the research study, you will be asked to sign this permission form. You are not giving up any of your child's legal rights by permitting him/her to take part in this research or by signing this parental permission form.

Who is conducting this research study?
Madonna Afriyie-Adams is the Principal Investigator of this research study.

Madonna Afriyie-Adams may be reached at phone number 347-782-2897 and address 2284 7th Avenue New York, NY 10030.

The Principal investigator or another member of the study team will also be asked to sign this informed consent. You will be given a copy of the signed consent form to keep.

Why is this study being done?
The purpose of this study is to see how a math computer program impacts students' performance in Algebra. The study will show if students' use of the program will result in higher math results than when learning math in a traditional classroom setting.

Who may take part in this study and who may not?
Students who are currently enrolled in Algebra I course may take part in the study.

Why has my child been asked to take part in this study?
Your child has been invited to take part in this study because he/she is currently enrolled in an Algebra I course.

How long will the study take and how many subjects will take part?
For this site, 30 students will participate in the study. Each students' participation will be 10 days for 10-30 minutes each day. For the entire study, there will be 150 students total participating in the study. The entire study will be 30 days.

What will my child be asked to do if s/he takes part in this study?
Each student will be asked to take a 10-question multiple choice math test to measure their math skills prior to the study. They will then be placed into one of three groups where they will receive 10 minutes of either instruction from a teacher or the MathConceptz system. Lastly, the students will take a 10-question multiple choice math test to measure their math skills after the study.

What are the risks and/or discomforts my child might experience by taking part in this study?
There are no foreseeable risks.

Are there any benefits to my child if s/he takes part in this study?
The benefits of taking part in this study may be that by receiving additional math support your child may improve in their mathematics knowledge.. However, it is possible that your child may not receive any direct benefit from taking part in this study.

What are my alternatives if I do not want to take part in this study?
Your alternative is not to allow your child to take part in this study.

How will I know if new information is learned that may affect whether I am willing to allow my child to stay in the study?
During the course of the study, you will be updated about any new information that may affect whether you are willing to allow your child to continue taking part in the study. If new information is learned that may affect your child after the study or their follow-up is completed, you will be contacted.

Will there be any cost for my child to take part in this study?
There will be no cost for your child to take part in this study.

Will my child be paid to take part in this study?
Your child will not be paid to take part in this study.

How will information about my child be kept private or confidential?
All efforts will be made to keep your child's personal information confidential, but total confidentiality cannot be guaranteed. Each student will be identified using an identification number. All data about the students will be stored according to a student identification number, and

on the password-protected computer of the researcher. Only the principal researcher has the username and password to access the computer files.

What will happen to my child's information or biospecimens collected for this research after the study is over?
The information collected about your child for this research will not be used by or distributed to investigators for other research.

What will happen if I do not wish my child to take part in the study or if I later decide that I do not wish my child to stay in the study?
It is your choice whether your child takes part in the research. You may choose to have your child take part, not to take part or you may change your mind and withdraw your child from the study at any time.

If you do not want your child to enter the study or decide to stop taking part, their relationship with the study staff will not change, and s/he may do so without penalty and without loss of benefits to which your child is otherwise entitled.

You may also withdraw your permission for the use of data already collected about you child, but you must do this in writing to Madonna Afriyie-Adams, 2284 Adam Clayton Powell Jr. Blvd, New York, NY 10030.

Who can I call if I have questions?
If you have questions about your child taking part in this study you can call the principal investigator: Madonna Afriyie at (347) 782-2897.

If you have questions about your child's rights as a research subject, you can call the IRB Director at: New Brunswick/Piscataway HealthSci IRB (732)235-9806 or the Rutgers Human Subjects Protection Program at (973) 972-1149.

PARENTAL PERMISSION FOR CHILD

I have read this entire form, or it has been read to me, and I believe that I understand what has been discussed. All of my questions about this form or this study have been answered.

I am the [ ] parent or [ ] legal guardian of _______________ (name of child) and I agree for my child to take part in this research study.

Subject/Child's Name:

Parent's Signature: Date:

Signature of Investigator/Individual Obtaining Consent:

To the best of my ability, I have explained and discussed the full contents of the study including all of the information contained in this consent form. All questions of the research subject and those of his/her parent or legal guardian have been accurately answered.

Investigator/pPerson Obtaining Consent:

Signature: Date: ____________________________

Child Assent Form

ASSENT TO TAKE PART IN A RESEARCH STUDY

TITLE OF STUDY: MathConceptz - Improving Math Performance
Principal Investigator: Madonna Afriyie-Adams, Doctoral Candidate

Who are you and why are you meeting with me?

I am Madonna Afriyie-Adams and I work at the Rutgers, The State University of New Jersey, in the Graduate School of Education. I am the investigator on a research project. Sometimes other people will work with me. We would like to tell you about a study that involves children like yourself. We would like to see if you would like to participate in this study.

What is this research study about?

I am doing this study to try out a new online program that teaches Algebra. I am seeing if the program helps you learn Algebra.

Why have I been asked to take part in this study?

You are invited to take part in the study because you are in an Algebra class.

Who can be in this study? And who may not? How long will the study take?

Students who are in Algebra classes can be in the study. The study will take 10 days.

What will happen to me if I choose to be in this study?

If you choose to be in the study you will first take a pre-test that will show what you already know in Algebra. You will then be in one of three groups where you will either be in a class with your teacher, do the computer program, or both for 8 days to learn new math topics. Last you will take a post-test to see what you learned in Algebra.

Will I get better if I am in the study?

It is possible that you will learn more about Algebra.

Can something bad happen to me or will I feel uncomfortable if I take part in this study?

Sometimes things happen to people in research studies that may hurt them or make them feel bad. These are called risks. There are no anticipated risks in this study.

What if I don’t want to take part in this study?

You don't have to be in this study if you don't want to. No one will get angry or upset if you don't want to be in the study. Just tell us. And remember, you can change your mind later if you decide you don't want to be in the study anymore.

Will I be given anything to take part in this study?

There are no gifts given to take part in this study.

What if I have questions?

You can ask questions at any time. You can ask now. You can ask later. You can talk to me or you can talk to someone else at any time during the study. Here are the telephone numbers to reach us:

If you have questions about the study you can call the investigator at: 347-782-2897

If you have questions about your rights as a research subject, you can call the IRB Director at: New Brunswick/Piscataway HealthSci IRB (732)235-9806 or the Rutgers Human Subjects Protection Program at (973)972-1149.

What are my rights if I decide to take part in this research study?

You may ask questions about any part of the study at any time. Do not sign this form unless you have had a chance to ask questions and have been given answers to all of you questions and agree to take part in the study.

I have read this entire form, or it has been read to me, and I believe that I understand what has been talked about. All of my questions about this form and this study have been answered.

I agree to take part in this research study.

Subject Name:

Subject Signature: Date:

Signature of Investigator or Responsible Individual:

To the best of my ability, I have explained and discussed the full contents of the study, including all of the information contained in this consent form. All questions of the research subjects and those of his/her parent(s) or legal guardian have been accurately answered.

Investigator/Person Obtaining Consent:
Signature: Date:

Teacher Consent Form

CONSENT TO TAKE PART IN A RESEARCH STUDY

TITLE OF STUDY: MathConceptz - Improving Math Performance
Principal Investigator: Madonna Afriyie-Adams, Doctoral Candidate

STUDY SUMMARY: This consent form is part of an informed consent process for a research study and it will provide information that will help you decide whether you want to take part in this study. It is your choice to take part or not. The purpose of the research is to: test the impact of a computer-based math program on student math performance in Algebra. If you take part in the research, you will be asked to administer a pre- and post-test to a group of 30 students, use face-to-face instruction and a computer-based program to teach Algebra lessons to three groups of ten students. Each lesson will span 15 minutes over the course of eight days. Your time in the study will take thirty days in which you will spend 10 days with each group of students. There are no foreseen harms or burdens associated with taking part in the study. Possible benefits of taking part may be improved performance for your Algebra students and exposure to more effective strategies to teach Algebra conceptually. Your alternative to taking part in the research study is not to take part in it.

The information in this consent form will provide more details about the research study and what will be asked of you if you choose to take part in it. If you have any questions now or during the study, if you choose to take part, you should feel free to ask them and should expect to be given answers you completely understand. After all of your questions have been answered and you wish to take part in the research study, you will be asked to sign this consent form. You are not giving up any of your legal rights by agreeing to take part in this research or by signing this consent form.

Who is conducting this research study?
Madonna Afriyie-Adams is the Principal Investigator of this research study.

Madonna Afriyie-Adams may be reached at phone number 347-782-2897 and address 2284 7th Avenue New York, NY 10030.

The Principal investigator or another member of the study team will also be asked to sign this informed consent. You will be given a copy of the signed consent form to keep.

Why is this study being done?
The purpose of this study is to see how a math computer program impacts students' performance in Algebra. The study will show if students' use of the program will result in higher math results than when learning math in a traditional classroom setting.

Who may take part in this study and who may not?
Teachers who currently teach Algebra I may take part in the study.
Why have I been asked to take part in this study?

You have been asked to take part in the study because you currently teach Algebra I.

How long will the study take and how many subjects will take part?
For this site, 30 students and 1 teacher will participate in the study. The teacher's participation will be 30 days for 10-30 minutes each day. Each students' participation will be 10 days for 10-30 minutes each day. For the entire study, there will be 5 teachers and 150 students total participating in the study. The entire study will be 30 days.

What will I be asked to do if I take part in this study?
You will be asked to administer an already created 10-question multiple choice pre-test to students. You will then instruct three groups of ten students over the course of eight lessons. You will develop and facilitate 15-minute mini-lessons to one group. You will develop and facilitate 8-minute mini-lessons to the second group as well as oversee their use of the computer group over the course of eight lessons. For the last group, you will oversee their use of the computer program over the course of eight lessons. Lastly you will be asked to administer an already created 10-question multiple choice post-test.

What are the risks and/or discomforts I might experience if I take part in this study?
There are no foreseeable risks.

Are there any benefits to me if I choose to take part in this study?
The benefits of taking part in this study may be improved math performance for your Algebra students, as well as exposure to more effective strategies of teaching Algebra conceptually. However, it is possible that you may not receive any direct benefit from taking part in this study.

What are my alternatives if I do not want to take part in this study?
There are no alternative treatments available. Your alternative is not to take part in this study.

How will I know if new information is learned that may affect whether I am willing to stay in the study?
During the course of the study, you will be updated about any new information that may affect whether you are willing to continue taking part in the study. If new information is learned that may affect you after the study or your follow-up is completed, you will be contacted.

Will there be any cost to me to take part in this study?
There will be no cost for you to take part in this study.

Will I be paid to take part in this study?
You will not be paid to take part in this study.

How will information about me be kept private or confidential?
All efforts will be made to keep your personal information in your research record confidential, but total confidentiality cannot be guaranteed. Each teacher will be identified using an identification number. All data about the teachers will be stored according to a teacher identification number, and

on the password-protected computer of the researcher. Only the principal researcher has the username and password to access the computer files.

What will happen to my information or biospecimens collected for this research after the study is over?
The information collected about you for this research will not be used by or distributed to investigators for other research.

What will happen if I do not wish to take part in the study or if I later decide not to stay in the study?
It is your choice whether to take part in the research. You may choose to take part, not to take part or you may change your mind and withdraw from the study at any time.

If you do not want to enter the study or decide to stop taking part, your relationship with the study staff will not change, and you may do so without penalty and without loss of benefits to which you are otherwise entitled.

You may also withdraw your consent for the use of data already collected about you, but you must do this in writing to Madonna Afriyie-Adams, 2284 Adam Clayton Powell Jr. Blvd, New York, NY 10030.

Who can I call if I have questions?
If you have questions about your child taking part in this study you can call the principal investigator: Madonna Afriyie at (347) 782-2897.

If you have questions about your child's rights as a research subject, you can call the IRB Director at: New Brunswick/Piscataway HealthSci IRB (732)235-9806 or the Rutgers Human Subjects Protection Program at (973) 972-1149.

AGREEMENT TO PARTICIPATE

1. Subject consent:

I have read this entire consent form, or it has been read to me, and I believe that I understand what has been discussed. All of my questions about this form and this study have been answered. I agree to take part in this study.

Subject Name:

Subject Signature: Date:

2. Signature of Investigator/Individual Obtaining Consent:

To the best of my ability, I have explained and discussed all the important details about the study including all of the information contained in this consent form.

Investigator/Person Obtaining Consent (printed name):

Signature: Date:

Appendix D - Danielson Rubric

	Ineffective	Developing	Effective	Highly Effective
1a: Demonstrating Knowledge of Content and Pedagogy	In planning and practice, the teacher makes content errors or does not correct errors made by students. The teacher displays little understanding of prerequisite knowledge important to student learning of the content. The teacher displays little or no understanding of the range of pedagogical approaches suitable to student learning of the content.	The teacher is familiar with the important concepts in the discipline but displays a lack of awareness of how these concepts relate to one another. The teacher indicates some awareness of prerequisite learning, although such knowledge may be inaccurate or incomplete. The teacher's plans and practice reflect a limited range of pedagogical approaches to the discipline or to the students.	The teacher displays solid knowledge of the important concepts in the discipline and how these relate to one another. The teacher demonstrates accurate understanding of prerequisite relationships among topics. The teacher's plans and practice reflect familiarity with a wide range of effective pedagogical approaches in the subject.	The teacher displays extensive knowledge of the important concepts in the discipline and how these relate both to one another and to other disciplines. The teacher demonstrates understanding of prerequisite relationships among topics and concepts and understands the link to necessary cognitive structures that ensure student understanding. The teacher's plans and practice reflect familiarity with a wide range of effective pedagogical approaches in the discipline and the ability to anticipate student misconceptions.
Critical Attributes	• The teacher makes content errors. • The teacher does not consider prerequisite relationships when planning. • The teacher's plans use inappropriate strategies for the discipline.	• The teacher's understanding of the discipline is rudimentary. • The teacher's knowledge of prerequisite relationships is inaccurate or incomplete. • Lesson and unit plans use limited instructional strategies, and some are not suitable to the content.	• The teacher can identify important concepts of the discipline and their relationships to one another. • The teacher provides clear explanations of the content. • The teacher answers students' questions accurately and provides feedback that furthers their learning. • Instructional strategies in unit and lesson plans are entirely suitable to the content.	• The teacher cites intra- and interdisciplinary content relationships. • The teacher's plans demonstrate awareness of possible student misconception and how they can be addressed. • The teacher's plans reflect recent developments in content-related pedagogy.
Possible Examples ***1a***	• *The teacher says, "The official language of Brazil is Spanish, just like other South American countries."* • *The teacher says, "I don't understand why the math book has decimals in the same unit as fractions."* • *The teacher has his students copy dictionary definitions each week to help them learn to spell difficult words.* • *And others…*	• *The teacher plans lessons on area and perimeter independently of one another, without linking the concepts together.* • *The teacher plans to forge ahead with a lesson on addition with regrouping, even though some students have not fully grasped place value.* • *The teacher always plans the same routine to study spelling: pretest on Monday, copy the words five times each on Tuesday and Wednesday, test on Friday.* • *And others…*	• *The teacher's plan for area and perimeter invites students to determine the shape that will yield the largest area for a given perimeter.* • *The teacher has realized her students are not sure how to use a compass, and so she plans to have them practice that skill before introducing the activity on angle measurement.* • *The teacher plans to expand a unit on civics by having students simulate a court trial.* • *And others…*	• *In a unit on 19th-century literature, the teacher incorporates information about the history of the same period.* • *Before beginning a unit on the solar system, the teacher surveys the students on their beliefs about why it is hotter in the summer than in the winter.* • *And others…*

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	Ineffective	Developing	Effective	Highly Effective
1e: Designing Coherent Instruction	Learning activities are poorly aligned with the instructional outcomes, do not follow an organized progression, are not designed to engage students in active intellectual activity, and have unrealistic time allocations. Instructional groups are not suitable to the activities and offer no variety.	Some of the learning activities and materials are aligned with the instructional outcomes and represent moderate cognitive challenge, but with no differentiation for different students. Instructional groups partially support the activities, with some variety. The lesson or unit has a recognizable structure; but the progression of activities is uneven, with only some reasonable time allocations.	Most of the learning activities are aligned with the instructional outcomes and follow an organized progression suitable to groups of students. The learning activities have reasonable time allocations; they represent significant cognitive challenge, with some differentiation for different groups of students and varied use of instructional groups.	The sequence of learning activities follows a coherent sequence, is aligned to instructional goals, and is designed to engage students in high-level cognitive activity. These are appropriately differentiated for individual learners. Instructional groups are varied appropriately, with some opportunity for student choice
Critical Attributes	• Learning activities are boring and/or not well aligned to the instructional goals. • Materials are not engaging or do not meet instructional outcomes • Instructional groups do not support learning • Lesson plans are not structured or sequenced and are unrealistic in their expectations.	• Learning activities are moderately challenging. • Learning resources are suitable, but there is limited variety. • Instructional groups are random, or they only partially support objectives. • Lesson structure is uneven or may be unrealistic about time expectations.	• Learning activities are matched to instructional outcomes. • Activities provide opportunity for higher-level thinking. • The teacher provides a variety of appropriately challenging materials and resources. • Instructional student groups are organized thoughtfully to maximize learning and build on students' strengths. • The plan for the lesson or unit is well structured, with reasonable time allocations.	• Activities permit student choice. • Learning experiences connect to other disciplines. • The teacher provides a variety of appropriately challenging resources that are differentiated for students in the class. • Lesson plans differentiate for individual student needs.
Possible Examples ***1e***	• *After his ninth graders have memorized the parts of the microscope, the teacher plans to have them fill in a worksheet.* • *The teacher plans to use a 15-year-old textbook as the sole resource for a unit on communism.* • *The teacher organizes her class in rows, seating the students alphabetically; she plans to have students work all year in groups of four based on where they are sitting.* • *The teacher's lesson plans are written on sticky notes in his grade book; they indicate: lecture, activity, or text, along with page numbers in the text.* • *And others…*	• *After a mini-lesson, the teacher plans to have the whole class play a game to reinforce the skill she taught.* • *The teacher finds an atlas to use as a supplemental resource during the geography unit.* • *The teacher always lets students self-select a working group because they behave better when they can choose whom to sit with.* • *The teacher's lesson plans are well formatted, but the timing for many activities is too short to actually cover the concepts thoroughly.* • *The plan for the ELA lesson includes only passing attention to students' citing evidence from the text for their interpretation of the short story.* • *And others…*	• *The teacher reviews her learning activities with a reference to high- level "action verbs" and rewrites some of the activities to increase the challenge level.* • *The teacher creates a list of historical fiction titles that will expand her students' knowledge of the age of exploration.* • *The teacher plans for students to complete a project in small groups; he carefully selects group members by their reading level and learning style.* • *The teacher reviews lesson plans with her principal; they are well structured, with pacing times and activities clearly indicated.* • *The fourth-grade math unit plan focuses on the key concepts for that level.* • *And others...*	• *The teacher's unit on ecosystems lists a variety of challenging activities in a menu; the students choose those that suit their approach to learning.* • *While completing their projects, the students will have access to a wide variety of resources that the teacher has coded by reading level so that students can make the best selections.* • *After the cooperative group lesson, the students will reflect on their participation and make suggestions.* • *The lesson plan clearly indicates the concepts taught in the last few lessons; the teacher plans for his students to link the current lesson outcomes to those they previously learned.* • *The teacher has contributed to a curriculum map that organizes the ELA Common Core State Standards in tenth grade into a coherent curriculum.* • *And others...*

	Ineffective	Developing	Effective	Highly Effective
3b: Using Questioning and Discussion Techniques	The teacher's questions are of low cognitive challenge, with single correct responses, and are asked in rapid succession. Interaction between the teacher and students is predominantly recitation style, with the teacher mediating all questions and answers; the teacher accepts all contributions without asking students to explain their reasoning. Only a few students participate in the discussion.	The teacher's questions lead students through a single path of inquiry, with answers seemingly determined in advance. Alternatively, the teacher attempts to ask some questions designed to engage students in thinking, but only a few students are involved. The teacher attempts to engage all students in the discussion, to encourage them to respond to one another, and to explain their thinking, with uneven results.	While the teacher may use some low-level questions, he poses questions designed to promote student thinking and understanding. The teacher creates a genuine discussion among students, providing adequate time for students to respond and stepping aside when doing so is appropriate. The teacher challenges students to justify their thinking and successfully engages most students in the discussion, employing a range of strategies to ensure that most students are heard.	The teacher uses a variety or series of questions or prompts to challenge students cognitively, advance high-level thinking and discourse, and promote metacognition. Students formulate many questions, initiate topics, challenge one another's thinking, and make unsolicited contributions. Students themselves ensure that all voices are heard in the discussion.
Critical Attributes	• Questions are rapid-fire and convergent, with a single correct answer. • Questions do not invite student thinking. • All discussion is between the teacher and students; students are not invited to speak directly to one another. • The teacher does not ask students to explain their thinking. • Only a few students dominate the discussion.	• The teacher frames some questions designed to promote student thinking, but many have a single correct answer, and the teacher calls on students quickly. • The teacher invites students to respond directly to one another's ideas, but few students respond. • The teacher calls on many students, but only a small number actually participate in the discussion. • The teacher asks students to explain their reasoning, but only some students attempt to do so.	• The teacher uses open-ended questions, inviting students to think and/or offer multiple possible answers. • The teacher makes effective use of wait time. • Discussions enable students to talk to one another without ongoing mediation by teacher. • The teacher calls on most students, even those who don't initially volunteer. • Many students actively engage in the discussion. • The teacher asks students to justify their reasoning, and most attempt to do so.	• Students initiate higher-order questions. • The teacher builds on and uses student responses to questions in order to deepen student understanding. • Students extend the discussion, enriching it. • Students invite comments from their classmates during a discussion and challenge one another's thinking. • Virtually all students are engaged in the discussion.
Possible Examples ***3b***	• *All questions are of the "recitation" type, such as "What is 3 x 4?"* • *The teacher asks a question for which the answer is on the board; students respond by reading it.* • *The teacher calls only on students who have their hands up.* • *A student responds to a question with wrong information, and the teacher doesn't follow up.* • *And others…*	• *Many questions are of the "recitation" type, such as "How many members of the House of Representatives are there?"* • *The teacher asks, "Who has an idea about this?" The usual three students offer comments.* • *The teacher asks, "Maria, can you comment on Ian's idea?" but Maria does not respond or makes a comment directly to the teacher.* • *The teacher asks a student to explain his reasoning for why 13 is a prime number but does not follow up when the student falters.* • *And others…*	• *The teacher asks, "What might have happened if the colonists had not prevailed in the American war for independence?"* • *The teacher uses the plural form in asking questions, such as "What are some things you think might contribute to________?"* • *The teacher asks, "Maria, can you comment on Ian's idea?" and Maria responds directly to Ian.* • *The teacher poses a question, asking every student to write a brief response and then share it with a partner, before inviting a few to offer their ideas to the entire class.* • *The teacher asks students when they have formulated an answer to the question "Why do you think Huck Finn did_____?" to find the reason in the text and to explain their thinking to a neighbor.* • *And others…*	• *A student asks, "How many ways are there to get this answer?"* • *A student says to a classmate, "I don't think I agree with you on this, because…"* • *A student asks of other students, "Does anyone have another idea how we might figure this out?"* • *A student asks, "What if…?"* • *And others…*

	Ineffective	Developing	Effective	Highly Effective
3c: Engaging Students in Learning	The learning tasks/activities, materials, and resources are poorly aligned with the instructional outcomes, or require only rote responses, with only one approach possible. The groupings of students are unsuitable to the activities. The lesson has no clearly defined structure, or the pace of the lesson is too slow or rushed.	The learning tasks and activities are partially aligned with the instructional outcomes but require only minimal thinking by students and little opportunity for them to explain their thinking, allowing most students to be passive or merely compliant. The groupings of students are moderately suitable to the activities. The lesson has a recognizable structure; however, the pacing of the lesson may not provide students the time needed to be intellectually engaged or may be so slow that many students have a considerable amount of "downtime."	The learning tasks and activities are fully aligned with the instructional outcomes and are designed to challenge student thinking, inviting students to make their thinking visible. This technique results in active intellectual engagement by most students with important and challenging content, and with teacher scaffolding to support that engagement. The groupings of students are suitable to the activities. The lesson has a clearly defined structure, and the pacing of the lesson is appropriate, providing most students the time needed to be intellectually engaged.	Virtually all students are intellectually engaged in challenging content through well- designed learning tasks and activities that require complex thinking by students. The teacher provides suitable scaffolding and challenges students to explain their thinking. There is evidence of some student initiation of inquiry and student contributions to the exploration of important content; students may serve as resources for one another. The lesson has a clearly defined structure, and the pacing of the lesson provides students the time needed not only to intellectually engage with and reflect upon their learning but also to consolidate their understanding.
Critical Attributes	• Few students are intellectually engaged in the lesson. • Learning tasks/activities and materials require only recall or have a single correct response or method. • Instructional materials used are unsuitable to the lesson and/or the students. • The lesson drags or is rushed. • Only one type of instructional group is used (whole group, small groups) when variety would promote more student engagement.	• Some students are intellectually engaged in the lesson. • Learning tasks are a mix of those requiring thinking and those requiring recall. • Student engagement with the content is largely passive; the learning consists primarily of facts or procedures. • The materials and resources are partially aligned to the lesson objectives. • Few of the materials and resources require student thinking or ask students to explain their thinking. • The pacing of the lesson is uneven—suitable in parts but rushed or dragging in others. • The instructional groupings used are partially appropriate to the activities.	• Most students are intellectually engaged in the lesson. • Most learning tasks have multiple correct responses or approaches and/or encourage higher-order thinking. • Students are invited to explain their thinking as part of completing tasks. • Materials and resources support the learning goals and require intellectual engagement, as appropriate. • The pacing of the lesson provides students the time needed to be intellectually engaged. • The teacher uses groupings that are suitable to the lesson activities.	• Virtually all students are intellectually engaged in the lesson. • Lesson activities require high- level student thinking and explanations of their thinking. • Students take initiative to improve the lesson by (1) modifying a learning task to make it more meaningful or relevant to their needs, (2) suggesting modifications to the grouping patterns used, and/or (3) suggesting modifications or additions to the materials being used. • Students have an opportunity for reflection and closure on the lesson to consolidate their understanding.
Possible Examples **3c**	• *Most students disregard the assignment given by the teacher; it appears to be much too difficult for them.* • *Students fill out the lesson worksheet by copying words from the board.* • *Students are using math manipulative materials in a rote activity.* • *The teacher lectures for 45 minutes.* • *Most students don't have time to complete the assignment; the teacher moves on in the lesson.* • *And others…*	• *Students in only three of the five small groups are figuring out an answer to the assigned problem; the others seem to be unsure how they should proceed. Students are asked to fill in a worksheet, following an established procedure.* • *There is a recognizable beginning, middle, and end to the lesson.* • *The teacher lectures for 20 minutes and provides 15 minutes for the students to write an essay; not all students are able to complete it.* • *And others…*	• *Five students (out of 27) have finished an assignment early and begin talking among themselves; the teacher assigns a follow-up activity.* • *Students are asked to formulate a hypothesis about what might happen if the American voting system allowed for the direct election of presidents and to explain their reasoning.* • *Students are given a task to do independently, then to discuss with a table group, followed by a reporting from each table.* • *Students are asked to create different representations of a large number using a variety of manipulative materials.* • *The lesson is neither rushed nor does it drag.* • *And others…*	• *Students are asked to write an essay in the style of Hemingway and to describe which aspects of his style they have incorporated. Students determine which of several tools—e.g., a protractor, spreadsheet, or graphing calculator—would be most suitable to solve a math problem.* • *A student asks whether they might remain in their small groups to complete another section of the activity, rather than work independently.* • *Students identify or create their own learning materials.* • *Students summarize their learning from the lesson.* • *And others…*

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	Ineffective	Developing	Effective	Highly Effective
3d: Using Assessment in Instruction	Students do not appear to be aware of the assessment criteria, and there is little or no monitoring of student learning; feedback is absent or of poor quality. Students do not engage in self- or peer assessment.	Students appear to be only partially aware of the assessment criteria, and the teacher monitors student learning for the class as a whole. Questions and assessments are rarely used to diagnose evidence of learning. Feedback to students is general, and few students assess their own work.	Students appear to be aware of the assessment criteria, and the teacher monitors student learning for groups of students. Questions and assessments are regularly used to diagnose evidence of learning. Teacher feedback to groups of students is accurate and specific; some students engage in self- assessment.	Assessment is fully integrated into instruction, through extensive use of formative assessment. Students appear to be aware of, and there is some evidence that they have contributed to, the assessment criteria. Questions and assessments are used regularly to diagnose evidence of learning by individual students. A variety of forms of feedback, from both teacher and peers, is accurate and specific and advances learning. Students self-assess and monitor their own progress. The teacher successfully differentiates instruction to address individual students' misunderstandings.
Critical Attributes	• The teacher gives no indication of what high-quality work looks like. • The teacher makes no effort to determine whether students understand the lesson. • Students receive no feedback, or feedback is global or directed to only one student. • The teacher does not ask students to evaluate their own or classmates' work.	• There is little evidence that the students understand how their work will be evaluated. • The teacher monitors understanding through a single method, or without eliciting evidence of understanding from students. • Feedback to students is vague and not oriented toward future improvement of work. • The teacher makes only minor attempts to engage students in self- or peer assessment.	• The teacher makes the standards of high-quality work clear to students. • The teacher elicits evidence of student understanding. • Students are invited to assess their own work and make improvements; most of them do so. • Feedback includes specific and timely guidance, at least for groups of students.	• Students indicate that they clearly understand the characteristics of high-quality work, and there is evidence that students have helped establish the evaluation criteria. • The teacher is constantly "taking the pulse" of the class; monitoring of student understanding is sophisticated and continuous and makes use of strategies to elicit information about individual student understanding. • Students monitor their own understanding, either on their own initiative or as a result of tasks set by the teacher. • High-quality feedback comes from many sources, including students; it is specific and focused on improvement.
Possible Examples	• *A student asks, "How is this assignment going to be graded?"* • *A student asks, "Is this the right way to solve this problem?" but receives no information from the teacher.* • *The teacher forges ahead with a presentation without checking for understanding.* *After the students present their research on globalization, the teacher tells them their letter grade; when students ask how he arrived at the grade, the teacher responds, "After all these years in education, I just know what grade to give."* • *And others…*	• *The teacher asks, "Does anyone have a question?"* • *When a student completes a problem on the board, the teacher corrects the student's work without explaining why.* • *The teacher says, "Good job, everyone."* *The teacher, after receiving a correct response from one student, continues without ascertaining whether other students understand the concept.* • *The students receive their tests back; each one is simply marked with a letter grade at the top.* • *And others…*	• *The teacher circulates during small- group or independent work, offering suggestions to students.* • *The teacher uses specifically formulated questions to elicit evidence of student understanding.* • *The teacher asks students to look over their papers to correct their errors; most of them engage in this task.* • *And others…*	• *The teacher reminds students of the characteristics of high-quality work, observing that the students themselves helped develop them.* • *While students are working, the teacher circulates, providing specific feedback to individual students.* *The teacher uses popsicle sticks or exit tickets to elicit evidence of individual student understanding.* • *Students offer feedback to their classmates on their work.* • *Students evaluate a piece of their writing against the writing rubric and confer with the teacher about how it could be improved.* • *And others…*

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Appendix E - Pre-Test and Post-Test

Pre-Test

1. In the equation $3x + 4 = 16$ what is the value of x?

1) $x = 3$
2) $x = 9$
3) $x = 4$
4) $x = 6$

2. The solution of the equation $5 - 2x = -4x - 7$ is

1) 1
2) 2
3) -2
4) -6

3. What is the product of $(x + 3)$ and $(x + 4)$?

1) $x^2 + 7x + 12$
2) $x^2 + 7x + 7$
3) $x^2 + 12x + 7$
4) $x^2 + 12x + 12$

4. The area of a rectangular garden is represented by $x^2 - 9x + 8$. The length and width of the garden is

1) $(x + 1)$ and $(x + 8)$
2) $(x - 1)$ and $(x - 8)$
3) $(x + 1)$ and $(x - 8)$
4) $(x - 1)$ and $(x + 8)$

5. Which equation has the same solutions as $2x^2 + x - 3 = 0$

1) $(2x - 1)(x + 3) = 0$
2) $(2x + 1)(x - 3) = 0$
3) $(2x + 3)(x - 1) = 0$
4) $(2x - 3)(x + 1) = 0$

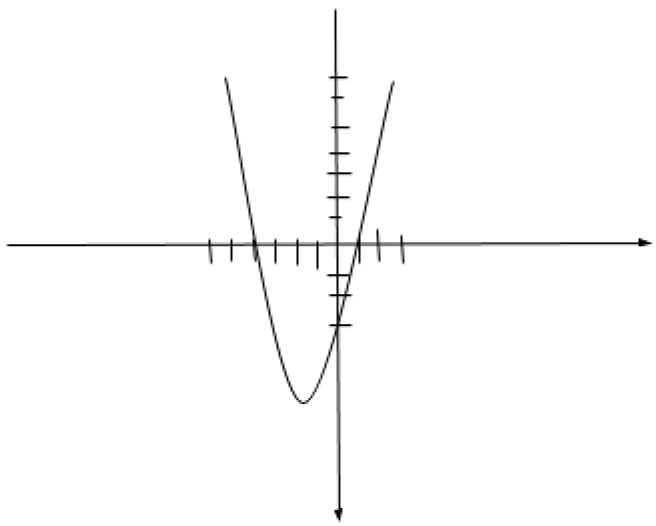
6. The function $r(x)$ is defined by the expression $x^2 + 3x - 18$. Use factoring to determine the zeros of $r(x)$.

1) 6 and 3
2) 6 and -3

3) -6 and 3
4) -6 and -3

7. The zeros of the function are

1) 4 and -1
2) -4 and 1
3) 7 and -3
4) -7 and 3



8. The zeros of the function $f(x) = 3x^2 - 3x - 6$ are

1) -1 and -2
2) 1 and -2
3) 1 and 2
4) -1 and 2

9. Solve $5x + 1 = 2x + 7$ in two ways.

a. Algebraically with equations.
b. Visually with pictures of a balance.

10. Make up a linear equation that has no solutions. Show how you would solve the equation with a visual of a balance.

Post-Test

1. In the equation $5x - 8 = 12$ what is the value of x?

    1) $x = 4$
    2) $x = 2$
    3) $x = -4$
    4) $x = -2$

2. The solution of the equation $8p + 2 = 4p - 10$ is

    1) 1
    2) -1
    3) 3
    4) -3

3. What is the product of $(x + 6)$ and $(x + 2)$?

    1) $x^2 + 12x + 12$
    2) $x^2 + 8x + 12$
    3) $x^2 + 12x + 8$
    4) $x^2 + 8x + 8$

4. The area of a rectangular garden is represented by $x^2 - 6x + 8$. The length and width of the garden is

    1) $(x + 4)$ and $(x + 2)$
    2) $(x - 4)$ and $(x - 2)$
    3) $(x + 4)$ and $(x - 2)$
    4) $(x - 4)$ and $(x + 2)$

5. Which equation has the same solutions as $x^2 - 10x - 24 = 0$

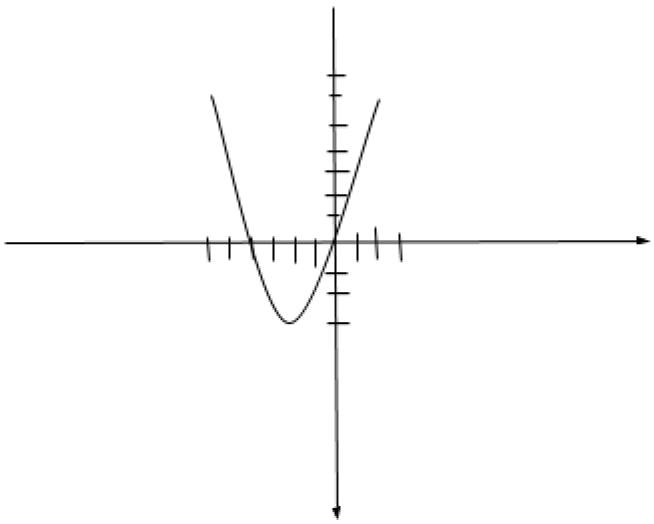
    1) $(x - 4)(x + 6) = 0$
    2) $(x - 4)(x - 6) = 0$
    3) $(x - 12)(x + 2) = 0$
    4) $(x + 12)(x - 2) = 0$

6. The function r(x) is defined by the expression $x^2 + 9x - 22$. Use factoring to determine the zeros of r(x).

    1) 11 and 2
    2) -11 and 2
    3) -11 and -2
    4) 11 and -2

7. The zeros of the function are

1) 4 and 0
2) -4 and 0
3) 6 and -4
4) -6 and 4



8. The zeros of the function $f(x) = x^2 - 2x - 24$ are

1) -8 and 3
2) -6 and 4
3) -4 and 6
4) -3 and 8

9. Solve $5x + 1 = 2x + 7$ in two ways.

a. Algebraically with equations.
b. Visually with pictures of a balance.

10. Make up a linear equation that has no solutions. Show how you would solve the equation with a visual of a balance.