Mathematical self-efficacy and understanding: using geographic information systems to mediate urban high school students' real-world problem solving

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MATHEMATICAL SELF-EFFICACY AND UNDERSTANDING: USING GEOGRAPHIC INFORMATION SYSTEMS TO MEDIATE URBAN HIGH SCHOOL STUDENTS’ REAL-WORLD PROBLEM SOLVING

Dissertation
by
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submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

August 2013
MATHEMATICAL SELF-EFFICACY AND UNDERSTANDING: USING GIS TO MEDIATE URBAN HIGH SCHOOL STUDENTS’ REAL-WORLD PROBLEM SOLVING

By Dennis J. DeBay

Lillie Richardson Albert, Ph.D., Chair

Abstract

To explore student mathematical self-efficacy and understanding of graphical data, this dissertation examines students solving real-world problems in their neighborhood, mediated by professional urban planning technologies. As states and schools are working on the alignment of the Common Core State Standards for Mathematics (CCSSM), traditional approaches to mathematics education that involves learning specific skills devoid of context will be challenged. For a student to be considered mathematically proficient according to the CCSSM, they must be able to understand mathematical models of real-world data, be proficient problem solvers and use appropriate technologies (tools) to be successful. This has proven to be difficult for all students—specifically for underrepresented students who have fallen behind in many of the Science, Technology, Engineering and Mathematics (STEM) fields.

This mixed-method design involved survey and case-study research to collect and examine data over a two-year period. During the first year of this study, pre- and post-surveys using Likert-scale questions to all students in the urban planning project (n=62). During the two years, ten high school students' mathematical experiences while investigating urban planning projects in their own neighborhoods were explored through interviews, observations, and an examination of artifacts (e.g. presentations and worksheets) in order to develop the case studies.

Findings indicate that real-world mathematical tasks that are mediated by professional technologies influence both students’ mathematical self-efficacy and understanding. Student self-efficacy was impacted by causing a shift in students beliefs about their own mathematical ability
by having students interest increase through solving mathematical tasks that are rooted in meaningful, real-world contexts; students’ belief that they can succeed in real-world mathematical tasks; and a shift in students’ beliefs regarding the definition of ‘doing mathematics’. Results in light of mathematical understanding demonstrate that students’ increased understanding was influenced by the ability to use multiple representations of data, making connections between the data and the physical site that was studied and the ability to communicate their findings to others. Implications for informal and formal learning, use of GIS in mathematics classrooms, and future research are discussed.
DEDICATION

This study is dedicated to

The SSJY Students

Marlene DeBay
Jim DeBay
My parents and favorite teachers

Molly Sullivan
The most amazing support

Dr. Lillie R. Albert
My mentor and friend
Acknowledgement

Although the following dissertation is an individual work, it would have been impossible to reach the heights or explored the depths without the support, help and guidance of many people. First, I would like to thank my mentor, advisor, dissertation chair and friend, Dr. Lillie Richardson Albert for instilling in me the qualities of being a good mathematics educator and researcher. Her enthusiasm and unique mentoring have been a major driving force throughout both graduate degrees at Boston College. Dr. Albert, thank you does not begin to express my deep gratitude for your guidance. The development of the study was, in large part, made possible by the tireless efforts of Dr. Mike Barnett. His belief that there are no ideas that are too crazy when trying to inspire student interest in the sciences, allowed me the opportunity to be as creative as necessary to make this project happen.

To my committee members, Dr. Alan Kafka and Dr. Michael Bowen, thank you’re your constructive feedback was supportive and allowed for this project to be understandable both within and outside of the field of mathematics education. Your insights were invaluable and remain embedded in the context of this work.

To Amy Anderson at Placeways LLC. Your technical support throughout the Urban Planning Project was unparalleled. Without you, we would have never figured out the intricacies of CommunityViz. The students (and many of us) would have never been able to get off the ground using this technology without your assistance. Your support throughout the defense presentation as well as the defense helped make this all possible.

To Rob Moray, the ultimate teaching and research assistant. This data would never have been analyzed without your help.
I would also like to thank my Boston College colleagues and friends for sharing the strains and stresses of a challenging and rigorous experience.

Last, but certainly not least, I want to thank my family and friends for your constant support and encouragement.
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CHAPTER 1
INTRODUCTION

Statement of the Problem

“Give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking; learning naturally results.” – John Dewey

Across the country, educational stakeholders have been exploring ways to align their mathematics programs with the recently implemented Common Core State Standards in Mathematics (CCSSM). As these Standards for Mathematical Practice call for a greater emphasis on mathematical modeling, students will be assessed on their ability to solve a variety of open-ended problems that involve analyzing real-world data. Textbooks and math resources advertise their “real-world problem solving” exercises and “real-life math applications.” However, as many mathematics educators can attest, the real-world examples are often contrived or forced and thus less interesting to students. For example, how many students truly care what time two trains leaving from New York and Detroit are going to cross paths? As the Common Core specifically states in the Standards of Mathematical Practice, “Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace.”

Interpreting data graphically is a relatively new and modern mathematical science. As actions and decisions are increasingly made on the basis of statistical information, graphs have become ever more important to industry, business, government and education (Council of Chief State School Officers, 2010; Shaughnessy & Zawojewski, 1999). Furthermore, with advancements in technology, computers and mobile devices are streaming a 24-hour news cycle, with journals, magazines, newspapers, and various other media outlets, also using graphs frequently. As a result, the ability to interpret data has become essential in the everyday lives of
informed citizens and in the workplace (Shaughnessy & Zawojewski, 1999). Many have had the experience of opening a well-known national news magazine and puzzling over a chart or graph, trying to figure out what it is supposed to tell the reader. The ability to read and understand information transmitted by different technologies has become increasingly important in schools.

Technology in education is not a new issue nor a recent phenomenon (Collins & Halverson, 2009; Cuban, 2001). In order to prepare for a successful career, students need to develop expertise using technologies in classrooms more than ever before. In addition to the computational power of computers and professional technologies, these tools also provide exciting new ways of sharing data, information, and ideas (Geiger, Forgasz, Tan, Calder, & Hill, 2012). Through these technologies, the modern mathematics classroom is no longer necessarily restricted to the chalkboard and the physical walls; now, students can analyze data through interesting, real-world mathematical tasks (Geiger, et al., 2012; Sorensen, 1996; Tall, 2012). Visualizing data using technologies can facilitate the development of mathematical and scientific understanding of real-world problems (Kim, Hannafin, & Bryan, 2007; Tall, 2012). Further, the growing power of computers, coupled with the availability of sophisticated software, has created opportunities to engage students in inquiry through the visualization of data (Vogel et al., 2006).

Informed citizens increasingly need to understand graphing practices in order to see the truth about data in the media, schools and in the world around us. Visual representations of data become important to sum up and convey information as well as stimulate ideas. Moreover, the construction of data displays is as much about reasoning about statistical evidence as it is about displaying statistical information effectively. Students’ success depends heavily on their ability to understand the imagery used and the conventions applied. Due to advancements in technology, understanding data has increasingly become more important in a variety of
disciplines, fields, and careers. Because of the prevalence of graphs and technology in our society and increased call for interpreting data in national standards (Council of Chief State School Officers, 2010; NCTM, 2000a), schools have required that all students work with and interpret real-world data. Because of the opportunities and the significance of understanding the content in order to understand media outlets and research, schools must decrease the gap of data interpretation achievement between students in and out of urban areas. Research professionals know that data do not speak for themselves; the right questions need to be asked. Exploring the data through descriptive and inferential analyses enables individuals to obtain answers to research questions. Data analysis, however, is only one step in the process; people must then be able to interpret the findings of their analyses, reporting them in such a way that others can make sense of the results and put them to use (Lapp & Cyrus, 2000).

Many researchers of mathematics education have focused on the achievement gap between urban students and their counterparts (Gningue, 2003; P. C. Walker & Chappell, 1997; S. Walker & Senger, 2007). Unfortunately, researchers have not devoted enough attention to understanding the interpretations of data performance for urban students. Educational researchers need to address this problematic gap in the literature.

Although a trend in mathematics education research states that studying graphs can lead to a deeper understanding of physical phenomenon through data (Dunham & Osborne, 1991; Goldberg & Anderson, 1989), students often struggle with understanding graphing and modeling data collected from real-life situations (P.H. Dunham & T.P. Dick, 1994). Mathematics education literature identifies several factors that increase students’ understanding of graphical interpretations of data (Lapp & Cyrus, 2000; Leinhardt, Zaslavsky, & Stein, 1990). However,
there is a dearth of information about how meaningful, real life connections to mathematical problems can positively influence urban students’ understanding (DeBay et al., 2012).

Because urban students have a unique perspective on the problems in their local communities, they are in a strong position to think about the urbanization of their neighborhoods as a meaningful problem to which they can find solutions. Urban renewal is a timely issue that cannot be viewed in isolation by the urban planners. Current processes to design and renew urban spaces and facilities do not incorporate data from key stakeholders: residents of these urban neighborhoods. It is critical to encourage our youth to become engaged in the process of urban renewal by demonstrating that their input has value. Just as planners do not have the background to fully appreciate the needs or wants of an area under revitalization, young people do not have the background knowledge or scientific and mathematics skills necessary for urban planning. Furthermore, students do not appreciate the costs attached to allocating parks, green space and playgrounds that promote a safe and healthy neighborhood. This can only be changed by educating young people about best practices for revitalizing their urban homes. Although the students have a meaningful connection to their neighborhoods, one of the reasons that they are not involved in the urban planning process is that they are missing the necessary understanding of the technology and analysis of data needed for effective urban planning.

In order to engage students, however, it is critical for teachers to encourage them to become active in the urban planning process, which may also foster pride in their communities. Although these students may have meaningful connections to their neighborhood, they do not understand the technology used by urban planners or the graphs that represent the data generated by these technologies. Helping these students understand graphs gives them a way to apply education to their real-world problems.
The intention of this project involving real-life mathematical tasks is to explore urban students’ self-efficacy and understanding of graphical interpretations of data with the assistance of computer technologies such as ArcView’s Geospatial Information Systems (GIS) and Microsoft Office’s Excel spreadsheet technology for urban planning. Building on research related to graphing literacy – or interpreting graphs from real-world connections – this study involves a pre and post survey to assist with bounded interpretive case studies of 10 high school students creating urban planning simulations for vacant lots in the greater Boston area.

This study was part of a larger NSF funded program (Grant # 0833624) with a focus on student Science, Technology, Engineering and Mathematics (STEM) development. Thus far, the urban planning program has focused on students’ understanding of the importance of sustainability and green space in urban areas. There has been little research on the mathematical or scientific skills students have learned (Middleton & Spanias, 1999). In previous iterations of the urban planning project, students struggled with reading and explaining graphs; thus, a major goal of this project was to assist students with the understanding of interpretation of graphical data. During the spring of 2011, students involved in the Students for Social Justice (SSJY) program at a college in Northeastern United States were asked to collect and analyze urban-planning data. The data was collected in an effort to assess the environmental impact of redesigning vacant lots in nearby communities to be better utilized by the city and residents as a whole. For their final project, the students developed group presentations intended to display their findings. The students used Pasco© probeware, iPads, and Microsoft Excel to collect and analyze temperature, sound, and lead levels within the vacant lot. During the final presentations, the research team noted that the students were not confident because they did not understand the information that the given graph was conveying. As a result, the research team created a
curricular unit for the SSJY summer institute to assist students with making connections between the sites that they studied and the graphs they created as well as to give students tools to help interpret graphical representations.

**Purpose of Study**

The purpose of this bounded case study was to investigate the influence of GIS technologies on 62 high school students’ mathematical self-efficacy and understanding of graphical representations of data in an urban planning exercise in the students’ own neighborhood. The research team created a technologically rich intervention for the SSJY program that involved exploring mathematical understanding of interpretation of the graphical representations through the use of GIS and Excel technologies. The use of Excel and GIS technology and analysis of computer modeling—using graphical interpretations—influenced SSJY students’ ability to understand environmental, physical and ecological changes in their own neighborhoods, which in turn influenced their final presentations. Therefore, this study will start with baseline information of students’ mathematical understanding from previous presentations and utilize data from class and field observations, semi-structured interviews with students, as well as a pre- and post-survey. This data will be utilized to assess and explain how the addition of this curriculum influenced students’ understanding of how data is connected with the sites being studied, the ability to convey that information to others and to assess whether students’ understanding of interpreting graphs has improved.

**Research Questions**

To test both mathematical self-efficacy and understanding, the researcher developed a specific SSJY learning environment in which 62 students had an opportunity to become “urban planners.” These students participated in activities which involved asking important questions
about the graphs that they are creating. In this research study, the goal was to analyze the self-efficacy and mathematical understanding of the participants in the SSJY program; therefore, the overarching question for the proposed research is:

1. How does involving SSJY high school students in real-world, meaningful mathematical urban planning projects in their own neighborhoods influence their mathematical understanding of graphical representations?

In addition, two sub-questions will be addressed:

a) How does the implementation of GIS and EXCEL technology in the SSJY program influence self-efficacy as students interpret graphical representations of data?

b) How is the mathematical understanding of graphical representations influenced by the introduction of GIS and EXCEL technology in the SSJY program?

**Importance of Study**

This study highlights several emerging areas of mathematics education. Given the importance of learning mathematics according to national standards (Council of Chief State School Officers, 2010; NCTM, 2000a), increased research is necessary to support students in using reasoning and sense-making and mathematical modeling to solve real-world mathematics. According to the CCSSM, “modeling is the process of choosing and using appropriate mathematics and statistics to analyses empirical situations, to understand them better, and to improve decisions.” (Council of Chief State School Officers, 2010, p. 72). Mathematics curricula must guide students toward the power of reasoning and sense making as they explore mathematical structures, of communication as they construct viable arguments, and of multiple representations as they engage in mathematical modeling.
In order to comprehend students’ mathematical understanding and how it fits within reform efforts, researchers have been searching for innovative techniques to collect and analyze data. One of the approaches that has come out of reform movement is using Activity Theory (Engeström, 1999) as a theoretical model to effectively build on students mathematical understanding (Roth, 2003). This theory provides the critical lens through which the study is being presented.

A final contribution of this study lies in the fact that it highlights snapshots of promise among urban students and their teachers. Recently, standardized tests have indicated that under-represented students in urban areas have not been successful in mathematics and, more specifically, solving problems that involve interpreting data (Rousseau & Tate, 2003). “Across many national surveys of student achievement, [urban] students remain largely over-represented in the lower tails of achievement distributions and underrepresented in the upper tails of these distributions” (Rousseau & Tate, 2003). In the 1983 National Assessment of Educational Progress (NAEP), results indicated that urban high school students were below the national average in data interpretation questions (House, 1993) – this trend does not seem to be changing. In their article, Rousseau and Tate (2003) reported that many of these students were not performing at acceptable levels in school mathematics. As a result of the increased usage of statistics and representing data in schools, more organizations are requiring that the students understand introductory statistics concepts. “The Curriculum and Evaluation Standards for School Mathematics has echoed the increased attention to statistics, reasoning and sense making as well as technology in society by recommending a prominent role for applications of data and chance in school mathematics” (Shaughnessy & Zawojewski, 1999).
Specifically, this dissertation used the data collected to capture students’ mathematical self-efficacy and understanding of graphical interpretations. The mixed-method approach of this study provided a more complete picture of mathematical understanding using activity theory as a tool for analysis.

**Theoretical Framework**

Activity theory (AT) is a social sciences theory pioneered by Alexei Leont'ev. Scholars using this theory seek to understand human activities as complex, socially situated phenomena. Activity theory is a descriptive framework that considers an entire work/activity system (including teams, organizations, etc.) beyond just one actor or user. It accounts for environment, history of the person, culture, role of the artifact, motivations, and complexity of real life activity, as seen in Figure 1.1.

![Activity Theory diagram](image)

*Figure 1.1. Activity Theory diagram*

One of the strengths of AT is that it bridges the gap between the individual subject and the social reality—it studies both through the mediating activity. The unit of analysis in AT is an object-oriented, collective, and culturally mediated human activity, or activity system. This system includes the object (or objective), subject, mediating artifacts (tools), rules, community, and division of labor. The motive for the activity in AT is created through the tensions and
contradictions within the elements of the system (Engeström, 1999). AT is particularly useful as a lens in qualitative research methodologies. AT provides a method of understanding and analyzing a phenomenon, finding patterns and making inferences across interactions. A particular activity is a goal-directed or purposeful interaction of a subject with an object through the use of tools.

Within AT, the unit of analysis is an activity system (AS) which refers to a group of people who share a common object (problem space) and who use tools to act and transform the object. Relationships in the AS are motivated by rules, which both assist and constrain behavior. Division of labor within the AS describes a horizontal division among community members, and a vertical division between power- and status-holders.

For this study, it is assumed that the introduction on GIS technology mediates the self-efficacy and mathematical understanding of students and has created a change in the activity system, challenging stabilized ways of acting on the object of the system and as a result required new ways of acting within the system. The Urban Planning project is considered the activity system; the instruction (subject) to assist with increasing the students’ self-efficacy and mathematical understanding or graphical interpretations (object) will be transformed using the GIS technology (mediating artifact) in order to arrive at better self-efficacy and mathematical understanding (outcome). The position of the intervention is influenced by rules of the SSJY program to use the technological environment. The community in this system includes the students, the SSJY instructors and the researcher that work together in the primary objects (student self-efficacy and mathematical understanding). These roles are part of the division of labor, with the students engaging with the technological environment and the instructors guiding the interaction. Please refer to Figure 1.2.
Figure 1.2. Activity Theory diagram for current study

Definition of Terms

For this study the following key terms are defined for transparency and comprehension of the research: what counts as doing mathematics, real-life context, mathematical modeling, Geographic Information Systems (GIS) technology, Activity Theory, self-efficacy and mathematical understanding.

Currently, many believe that *what counts as doing mathematics* involves what you learn in school and as long as you stay in school, you may eventually do what professional mathematicians do (Stevens, 2012). What this seems to suggest, is that there is a straight path through school into a profession. However, students spend most of their time outside of school. This raises the question – Do these activities count as mathematics? If they do not, this may suggest that school mathematics does not transfer out into the real-world. According to Stevens (2012) what counts as mathematics depends on how the culture represents mathematics and school is only one setting where mathematics is represented. As a result, looking at experiences where students can learn mathematics outside of school walls will also be necessary to make the connection between informal and formal mathematics experiences for students.
Within current mathematical reforms in education supported by both the new CCSSM and the National Council of Teachers of Mathematics (NCTM, 2000), conceptual understanding of mathematical ideas that connect reasoning and sense-making through problems that are contextually meaningful for students becomes increasingly important (NCTM, 2009). For this study, the term real-life context refers to the context of solving real world and mathematical problems, and represent …mathematical reasoning.” (Council of Chief State School Officers, 2010, p. 25). This process involves Mathematical Modeling which links classroom mathematics and statistics to everyday life, work, and decision-making. As mentioned in the Common Core Standards “Modeling is the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions” (Council of Chief State School Officers, 2010, p. 72).

Geographic information systems (GIS) is a type of software designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. In the case of this study, students are using a specific software suite named CommunityViz which is an extension of ESRI’s popular ArcGIS software application and provides a large suite of extra functions that combine with ArcGIS make a more specialized, powerful decision-making platform tool for setting up alternative futures (scenarios) and analyzing their effects; tools for making interactive three-dimensional (3-D) models of real places as they are now and as they could be in future; tools for explaining and communicating across the many groups of people who become involved in making urban planning decisions.

Activity Theory (AT) views learning as an ongoing process that develops as an individual interacts with the environment. It is the theoretical framework for this study. As a definition for this study, self-efficacy explains the judgments made and the potential to learn successfully and
the belief in one’s own capabilities (Bandura, 1997). Perceptions of self-efficacy come from personal accomplishments, vicarious learning experiences, verbal persuasions, and physiological states (Bandura, 1986). Self-efficacy involves affective, cognitive and conation domains. Self-efficacy is one of the most important constructs that influence mathematical understanding. In assessing students in mathematics, a problem we face is that we are all too often assessing only a limited part of their mathematics understanding. Hiebert and Carpenter (1992) specifically defined mathematical understanding as involving the building up of the conceptual context. Mathematical understanding for this study follows Carpenter’s (Hiebert & Carpenter, 1992) definition:

The mathematics is understood if its mental representation is part of a network of representations. The degree of understanding is determined by the number and strength of its connections. A mathematical idea, procedure, or fact is understood thoroughly if it is linked to existing networks with stronger or more numerous connections. (p. 67)

Having adopted a definition for understanding that involves ‘representations,’ we should now define what we mean by this. First, we should clarify that we are referring to mental or internal representations, using the definition from Davis (1984): “Any mathematical concept, or technique, or strategy – or anything else mathematical that involves either information or some means of processing information – if it is to be present in the mind at all, must be represented in some way” (p.203). This idea of understanding as a construct involves a structure of mathematical ideas or representations. Sierpinska (1994) clarified the issue of whether understanding is referred to as an action or as a result of an action by putting forward two different ways of looking at understanding. Initially, there is the act of understanding which is the cognitive experience associated with the connection of what is to be understood and the basis for that understanding. Secondly, the processes is the connection being made between acts of
understanding through reasoning processes, including developing explanations, learning by example, linking to previous knowledge, linking to figures of speech and carrying out practical and intellectual activities (Sierpinska, 1994).

**Researcher Positionality**

Culture and learning are integrally connected processes; for that reason, research on students learning through contextually meaningful tasks can have important cultural implications. These cultural implications come into play and impact the nature of research findings. Therefore, it is important to be cognizant of the researcher’s background and beliefs, as they can color the lens through which he interprets the world and research (Lather, 1986). My own cultural experiences influenced the way I gathered and interpreted this study’s data. The factors that color my world include my own personal background and my beliefs regarding the students that live and go to school in urban areas in the United States. In the interest of transparency, some comments on my positionality are presented below.

I am a white male, raised in a family in the suburban area of a city in Eastern Canada. I have had a privileged passage through formal education. The majority of my family members are educators who always stressed the importance of the never ending quest for knowledge. My parents were both teachers and my maternal grandparents worked in higher education. My family expected me to work hard and believed that the key to higher education and a bright future was succeeding in school. I was interested in mathematics and sciences mostly because I found it challenging; however, my love was music performance. My mathematics experience in high school was not an enjoyable one. I had the same teacher for all three years of mathematics, and he focused on the top percentile of students and winning mathematics competitions instead of ensuring that the entire class understood the key concepts. This lead to anxiety and frustration
in mathematics and pushed me further toward the arts and music, but I still believed that there had to be a better way to teach and learn mathematics.

I was very fortunate to attend a well-known Canadian university for a degree in music performance and the sciences. There I entered into the tutelage of a music theory professor. Knowing I was also involved in the sciences, he showed me the importance of mathematics in the context of music. This new context in mathematics engaged and interested me in learning. This lead me to take and enjoy mathematics courses so that I could apply what I was learning. After earning a degree in both music and mathematics, I felt the need to get a technical degree to “get a good job” in some field within information technology. This program helped me develop strategies for using technology and computer science in learning.

Following in my family’s footsteps, I moved to the Northeast United States to study mathematics education with the hope of generating student interest in mathematics by teaching it in context. After my Master’s degree, I taught mathematics and computer science in a suburban high school for four years. This school’s focus on “high stakes” testing and accountability made it very difficult to teach contextual mathematics outside of what was outlined and expected in the curriculum. This was a frustration that I was unsure how to resolve. At the suggestion of a friend, I applied to a position to become an instructor as part of the SSJY program. From this experience I learned about teaching students in urban districts and the barriers they face in furthering their education. In this informal learning experience, I had the opportunity to work with students in smaller classes and focus on how mathematics and science skills can be used in solving social justice problems in their own neighborhoods. I realized that in order to empower students in this way, I would need more schooling: thus, I applied and was accepted to a doctoral program in education to acquire the skills necessary to accomplish this goal. At this school I continued to
work with the SSJY students. My experience with the SSJY program solidified my view that all students can achieve and be interested in mathematics. It also convinced me that learning mathematics in context can play a major role in helping students reach their maximum potential. I am troubled by the fact that mathematical achievement is so inequitably distributed among student groups, and I believe that this problem can be remedied. This inequity motivates my desire to create effective, contextual, technology-driven learning environments for under-represented students.

**Overview of the Chapters**

This dissertation is comprised of six chapters. Chapter 1 presented an overview of this study. It framed the purpose of the study, provided a rationale and presented the research questions investigated. In Chapter 2, the literature impacting this study will be presented as it relates to the Activity Theory framework on student understanding and self-efficacy of graphical interpretations of data in terms of real-life, contextual, mathematical activities aided by the use of urban planning technologies. Chapter 3 outlines the methods and analysis of this investigation including the research design (Stake, 2000), data collection procedures, analysis framework and participants. Chapters 4 and 5 present findings related to student mathematical understanding and self-efficacy of urban high school students involved in the SSJY informal education program. Finally, Chapter 6 comments on the implications of this study for classroom practice, teacher education, and future avenues for research.
Chapter 2
LITERATURE REVIEW

Introduction

The review of literature addresses the exploration of urban high school students doing meaningful; contextualize mathematics, mediated by technology to influence their mathematical self-efficacy and understanding of interpreting graphs. This study was informed by five main bodies of literature: history of reforms in mathematics education, what it means to learn mathematics, activity theory, mathematical self-efficacy and finally mathematical understanding of interpreting graphs.

The first section locates this study in the field of mathematics education with an overview of the historical perspective on the reform movement and addresses its influence on curriculum, teaching and learning. The second section defines what it means to ‘do mathematics’ will be explained to understand differing views on mathematics learning and application. For the third section, a description of activity theory is presented as the lens for this study. This section also includes a review of major conceptual arguments and a sample of empirical studies that have applied activity theory to investigate issues related to learning mathematics and then more specifically to understanding graphical interpretations. The fourth section is a description and analysis of literature on mathematical self-efficacy and the role that it has on the fifth and final section, mathematical understanding all of which permeates the theme of real-world mathematics. These sections include influential conceptual studies on student mathematical understanding, followed by empirical studies related to understanding of how to interpret graphs from real-world data.

Taken together, these five bodies of literature provide a historical and theoretical context for this study. The literature addresses the problem of self-efficacy and mathematical
understanding for urban students in relation to meaningful contexts with the assistance of urban planning technologies. The final section summarizes the findings of the review and locates the research questions of this study within the context of the related literature.

**Historical Context of Reform in Mathematics Education**

The significance of this study can be found in the vast history of mathematics education. Over the last 200 years, there has been a call for reasoning and sense making of real-world problems (NCTM, 2009) and making meaningful connections across diverse mathematical ideas and contexts. Specifically, in more recent years, technology has been incorporated in classrooms to create representations of data and as a tool to assist with the understanding of mathematical concepts (Chinnappan & Thomas, 2000; Hiebert et al., 1997; Lapp & Cyrus, 2000). Even more so, research has shown that students in urban schools are in need of assistance when making these connections between mathematics and real-world examples as well as access to the technological tools that are needed in the current and future careers.

**History of Mathematics Reform**

Throughout the history of mathematics education and even in today’s classrooms the sentiment has been that currently, many students have difficulty because they find:

- mathematics meaningless…With purposeful attention and planning, teachers can hold all students in every…mathematics classroom accountable for personally engaging in reasoning and sense making, and thus lead students to experience reasoning for themselves rather than merely observe it. (NCTM, 2009, pp. 5-6)

Engagement and reasoning have become imperative for many of the jobs that students will be applying for today and in the future. In one of the very first mathematics teaching publications in North America it was noted that:

- It is very important for teachers to lead scholars into the habit of attending to the process going on in their own minds while solving questions, and of explaining how they solve
them. ….It is next to impossible for a person to direct another’s thoughts unless (s) he knows the channel in which they are already flowing.”—Warren Colburn, Teaching Arithmetic in the Method of Pestalozzi, 1830.

Nearly one hundred years later, a similar call in the United States was echoed:

Continued emphasis must be placed on the development of processes and principles in the solution of concrete problems, rather than on the acquisition of mere facility or skill in manipulation. The excessive emphasis now commonly placed on manipulation is one of the many obstacles to intelligent progress. (Requirements, 1923)

Not too much longer after that, William Brownell noted that “According to the meaning theory the ultimate purpose of instruction is the development of the ability to think in quantitative situations…Children must be able to analyze real or described quantities, and to make whatever adjustments are required by their solutions.” —William Brownell, Psychological Considerations, 1935

As a response to the low mathematics performance of pupils in the U.S., the National Council of Teachers of Mathematics (NCTM, 1980) published An Agenda for Action. This report made recommendations for instruction in mathematics to place a greater focus on problem solving rather than basic skills.

Students should be encouraged to question, experiment, estimate, explore, and suggest explanations. Problem solving, which is essentially a creative activity, cannot be built exclusively on routines, recipes, and formulas (NCTM, 1980, p. 4). To follow this up, in 2009 in their Focus on Reasoning and Sense Making, NCTM echoed their original thoughts by stating, “Reasoning and sense making are the foundations of the NCTM Process Standards in PSSM… Problem Solving, Communication, Connections, Reasoning and Proof, and Representations” (NCTM, 2009, p. 5).
There is a lot of common ground between NCTM’s Process Standards and the Common Core Mathematical Practices. There are strong connections between the messages in NCTM’s Focus in High School Reasoning and Sense Making materials, and the Common Core State Standards Mathematical Practices. These connections will be imperative to move mathematics education forward in today and tomorrow’s society.

In Adding It Up (Kilpatrick, Swafford, & Findell, 2001), reasoning and sense making are intertwined through many of the strands of mathematical proficiency. For example, procedural fluency includes learning with understanding and knowing which procedure to choose, when to choose it, and for what purpose. Without reasoning and sense making, students may come to view procedures as steps they are told to do rather than a series of steps they choose to do for a specific purpose on the basis of mathematical principles. Without understanding the basis of procedures in reasoning and sense making, they may be able to correctly perform those procedures but may think of them only as a list of “tricks.” As a result, they may have difficulty selecting the procedure to use in a given circumstance owing to a lack of understanding of what the procedure will accomplish. In terms of productive disposition (Kilpatrick, et al., 2001) students personally engage in mathematical reasoning and sense making as they are learning mathematics content.

The common core state standards: Reasoning and sense making. According to the NCTM, all high school mathematics programs should have an emphasis on real-world examples to prepare students for citizenship, work and further study (NCTM, 2000). With the increased demand for technology and mathematical literacy in the 21st century, students are challenged in all three areas of citizenship, work and study. Studies have shown that students in the United States are falling behind in their capacity “to analyze and reason as they pose, solve and interpret
problems in a variety of situations” (p. 7). The increased need for technology use in the workforce provides other challenges as the traditional mathematics curriculum will need to properly prepare students to use technology to enter many careers that need that technological knowledge (Friedman, 2006). As a result, the United States is also in danger of losing their global edge in terms of STEM (NRC, 2007).

In *High School Mathematics: Reasoning and Sense Making* (NCTM, 2009), reasoning is defined as, “The process of drawing conclusions on the basis of evidence or stated assumptions,” which is involved in the justification and generalization of mathematics learned in school. Sense making is defined as “Developing understanding of a situation, context, or concept by connecting it with existing knowledge” (NCTM, 2009), which is evident in the communication of thinking, connecting the mathematics and context and then connecting across different mathematical ideas.

Having an emphasis on real-world mathematical tasks in mathematics will give students the opportunity to accurately carry out mathematical procedures but more importantly, understand how these procedures work. The relationship between reasoning and sense making is shown in the following statement:

Mathematics has two faces. Presented in finished form, mathematics appears as a purely demonstrative [deductive] science, but mathematics in the making is a sort of experimental science. A correctly written mathematical paper is supposed to contain strict demonstrations only, but the creative work of the mathematician resembles the creative work of the naturalist; observation, analogy, and conjectural generalizations, or mere guesses … play an essential role in both. (Polya, 1954, p. 739)

This project, with its emphasis on real-world problems, spotlights key foundational elements of the CCSSM standards. In the CCSSM, there is an echo of being able to “Interpret functions that arise in applications in terms of the context” and “determine an explicit
expression, a recursive process, or steps for calculation from a context” (Council of Chief State School Officers, 2010).

**National council of teachers of mathematics: Mathematical modeling.** The reasoning processes of mathematics help us understand and operate in the physical and social worlds. Mathematical modeling is a process of connecting mathematics with a real-world context. The connections between mathematics and real-world problems developed in mathematical modeling add value to, and provide incentive and context for, studying mathematical topics. Mathematical modeling also offers opportunities to make connections among different mathematical areas, because in many situations, real-world problems require a combination of mathematical tools. The CCSSM (2010) include many of the ideas advocated by NCTM, selecting to highlight the importance of mathematical modeling by including it as one of the standards for Mathematical Practices. Specifically, this practice recommends that mathematically proficient students should be capable of categorizing essential

…quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas…They routinely interpret their mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose. (p. 7).

According to the CCSSM, statistical reasoning involves making conclusions from, and decisions based on, experimental data. Statistics gives students the tools for summarizing data and provides strategies for interpreting the meaning of the data within the context of the problem. Research exists that suggests that learning about data using social issues that are meaningful for students will foster learning (Beckett & Shaffer, 2005; Lapp & Cyrus, 2000; Shaffer, 2004). The American Statistical Association recommended using real-world data to enhance human welfare (Lesser, 2007). Not only are these illustrations practical, but they provide interesting topics that may motivate the students even though Schumm (2002) did not endorse just using social issues
and examples to teach statistics. However, they did provide a historical example that used a social aspect.

Other examples where the researcher used social issues to foster learning were while discussing the difference between constants and variables. Brzuzy and Segal (1996) suggest projects stressing service-learning and practicality could enhance comprehension (Brzuzy & Segal, 1996). Furthermore, Strand, Marullo, Cutforth, Stoecker, & Donohue (2003) support practical, community-based learning to deepen the students’ understanding.

According to Tall (2012), to harness the full potential of real-world mathematics, there needs to be an increase in technologies potential in classrooms. Tall believed that with time and effort, innovations in computational representations will make access to real-world, meaningful mathematics possible.

**Technology in mathematics standards.** Historically, educators have been proponents of incorporating new technologies into their classrooms. In 1913, Thomas Edison predicted that “books will soon be obsolete in the schools. . . . Our school system will be completely changed in ten years” (Saettler, 1990, p. 98). Sadly, the effect of technology in schools has been slight. It is believed that the failure of technology in educational settings occurs because of teacher interpretation of why the technology should be used. Technology should become the tool mediating the instruction instead of the sole method of instruction. In order to accomplish an increased, successful implementation of technology in classrooms, there needs to be further research into how technologies can be utilized in mathematics education settings to bring about positive beliefs about technology from the teachers and increased engagement and performance from the students (Cuban, 2001; Tall, 2012).
Cuban found few teachers who reached the "invention" level of technology integration, where teachers are able to find new ways to connect students to the content in the classroom. In his study, most elementary schools remained at the adoption level where teachers tend to take a more traditional approach to instruction but do provide some explanation of how to use technology. Cuban stated that the classrooms sustained a traditional model of instruction rather than being transformed. Through Cuban’s research there was no concrete evidence that revealed gains in engagement or achievement as the result of using technology. He concludes that many technologies have been oversold by policy makers and promoters, and underused by those in education. His vision for making the most of the new technologies reform to bring together teachers with parents, policy makers, corporate officials, and public officers to work on questions such as: how can technology build stronger communities and citizens and how can monies achieve larger social and civic goals? Cuban believes that computing technology "has yet to produce worthy outcomes" (Cuban, 2001, p. 197).

In the United States, the use of standards-based teaching and learning has become increasingly important. The success of mathematics taught in schools is based on these standards, and at the school level, school boards are holding schools accountable for teaching standards-based curriculum. In mathematics there are currently two main forums that dictate mathematics standards in the United States: the National Council for Teaching Mathematics (NCTM) and the CCSSM, both providing tools that are used to base the level of mathematics performance in classrooms, schools, districts, states and even the nation as a whole. To be well grounded in what is asked by both the NCTM and CCSSM and for technology to be properly integrated and used within these standards, research into their connections and relationships will be necessary.
The NCTM technology principle states, “Technology is an essential tool for learning mathematics in the 21st century, and all schools must ensure that all their students have access to technology” (NCTM, 2000a). The importance of technology involves effective teachers that maximize the potential of technology to develop students’ engagement and proficiency in mathematics (NCTM, 2000a). However, NCTM explains that the use of technology cannot replace conceptual understanding, computational fluency, or problem solving skills. In a balanced mathematics program, the strategic use of technology enhances mathematics teaching and learning. All schools and mathematics programs would ideally provide students and teachers with access to instructional technology, including appropriate calculators, computers with mathematical software, Internet connectivity, handheld data-collection devices, and interactive presentation devices. NCTM has also created the website “Illuminations” (NCTM, 2000a), which provides links to a variety of interactive mathematics activities for students at any grade-level.

The CCSSM standards (Council of Chief State School Officers, 2010) also presents technologies as tools, and not independent skill sets. Any mention of technology is found in overarching sections of the document. The CCSSM contains a general list of Standards for Mathematical Practice which includes processes and proficiencies important to all mathematical processes. It is only here that technology is mentioned for the entire document. The remainder of the document focuses on grade-specific Standards for Mathematical Content, listing the procedures and understandings students should have at that level. According to the CCSSM students should:

…consider the available tools when solving a mathematical problem. These tools might include pencil and paper, concrete models, a ruler, a protractor, a calculator, a spreadsheet, a computer algebra system, a statistical package, or dynamic geometry software. When making mathematical models, they know that
technology can enable them to visualize the results of varying assumptions, explore consequences, and compare predictions with data. (p.7)

Both the NCTM and CCSSM advocate for the integration of educational technology into academics instead of being taught as separate subjects. The standards include basic technology skills such as keyboarding that students must know to succeed, but in the bigger picture, they call for students to use technology to help them learn instead of just having technology in classrooms. Translating these technology standards into practice, can advance the goals of reasoning and sense making in the high school mathematics classroom. It can be particularly useful in assisting with finding patterns and relationships and forming conjectures (Shaffer, 2004). Technology can allow students to reflect on their progress toward solving a problem rather than on carrying out computations and to draw logical conclusions (Beckett & Shaffer, 2005; Lapp & Cyrus, 2000). A student’s ability to display multiple representations of the same problem using technology can aid in making connections. The incorporation of technology in the classroom should not overshadow the development of the procedural proficiency needed by students to support continued mathematical growth. It can, however, provide a lens that leads to a deeper understanding of mathematical concepts.

The Importance of Understanding Data

To be successful in understanding data a students need to be proficient in mathematics and be able to discern deeper meaning from the data; however, many urban students are not enrolling in higher-level mathematics courses to learning and possess the skills necessary to interpret the data (Rousseau & Tate, 2003). In a study conducted by Johnson and Kuennen (2006), the researchers found the strongest predictor of performance in interpreting data was a student’s GPA. What they found, was that students' previous experiences with mathematics influenced their basic mathematical skills. These basic skills were a significant predictor of
student success in the course and urban students performed significantly worse on the tests that involved these basic skills. Along with these skills and attributes, they found that important for urban students to be able to translate abstract ideas, analyze and change errors made and reduce fear of understanding data. There were several problems with graphing questions that proved difficult for students.

One issue was that with common word problems, students often have difficulties translating verbal problems into mathematical and statistical models (Garfield & Ahlgren, 1988). For many under represented students, the issue of a language barrier may create difficulties that are challenging to overcome. Oftentimes, translation and categorization are more difficult for story problems than for formula problems (Myers, Hansen, & Robson, 1983), coupled with the language problem “an important factor in misjudgment is a misperception of the question being asked” (Garfield & Ahlgren, 1988).

Second, because of previous exposure to working with data, many students have developed a lack of positive self-efficacy and distaste for the subject. Like so many other mathematics courses, students often start courses with anxiety and the lack of self-efficacy, which are often more exaggerated than the true difficulty of the subject matter warrants (Saxe & Esmonde, 2005). Saxe and Esmonde (2005) have found supporting evidence that too much anxiety can interfere with cognitive functioning.

One of the factors in this lack of positive self-efficacy comes from students’ misunderstanding of complex and abstract ideas. It has been suggested that half of the students in high school cannot think on a formal operation level. Thus, teachers may need to forego abstract ideas and instead convey statistical ideas in more simple and concrete terms (Garfield & Ahlgren, 1988). Teaching may be more effective if teachers understand what misconceptions the
students have. By understanding students’ preconceived ideas, teachers may be able to show the students where their misconceptions conflict with the definitions of probability (Madsen, 1995). Along with posing careful questions, Myers, et al. (1983) hint that placing keywords and removing irrelevant information will aide in the understanding of statistics.

In order to comprehend students’ mathematical understanding and how it fits within reform efforts, researchers have been thinking of innovative techniques to collect and analyze data. One of the approaches that have come out of the mathematics education reform movement is using Activity Theory as a theoretical model to effectively start to build on students’ mathematical understanding.

**What is “Learning Mathematics”?**

“The presumptions of meaning are based on community, purpose, and situation. It is futile to discuss the meaning of a word or term in isolation from the discourse community of which the speaker claims membership, from the purpose of the speaker, or from the specific situation in which the word was spoken. Indeed, it is not the word that has meaning, but the utterance” (Clarke, 1998, pp. 99-100).

Drawing on socio-cultural theory, we understand the norms regulating the learning of mathematics both in and out of the mathematics classroom as resulting from the social representations of the school culture related to what constitutes learning mathematics (Vygotsky, 1978). All students, having their own personal histories as members of particular social groups, and having been in school traditions have their own images of what mathematics is about. The view of mathematics as a form of cultural knowledge challenged the traditional explanations of the relationship between school and home mathematics in terms of dichotomies, such as theoretical versus practical knowledge and abstract versus concrete reasoning (Abreu, 1995).

"In-school" and "out-of-school" mathematics education practices continue to evolve through globalization and through the use of technology. As these practices develop and as adult
education and life-long education grow in importance, along with their mathematical versions, there is an increasing need for mathematics education to move away from ideas and practices based on traditional theories and normative ideas. This is particularly important if research in mathematics education is to continue to have relevance and influence. In the last two decades educational and psychological research studies on social, cultural and political aspects of mathematics learning, have indicated the potential of this field for informing and developing teaching practices at all levels of mathematics education (Lave, 1993; Moses & Cobb, 2001). With regard to the relation between school and out-of-school mathematics, most research shows a strong discontinuity between school and out-of-school mathematical practice. According to early work on situated cognition, e.g. Lave (1993), this discontinuity is a consequence of learning in and out of school being two distinct social practices. School mathematics, moreover, is often not suited to out-of-school practices: in some cases out-of school problems are only apparently similar to school mathematics problems, but in reality there is a range of explicit and implicit restrictions which makes school methods unsuitable and thus other methods are used.

Schools play a critical role in learning and development, however children and youth spend the majority of their time outside of school (Larson & Verma, 1999). One large portion of out-of-school time occurs in the summer, which represents an opportunity for experiences that enrich and complement the school year and promote learning and development. During the summer, low-income and other urban students fall further behind academically than their more advantaged peers - in part, due to a lack of enriching opportunities (Heyns, 1978). Academically focused summer programs can meet this need and promote learning when school is not in session (Fairchild, 2006).
Extra-curricular mathematical activities can have a number of different objectives, but their essential purpose is to supplement the mathematics education provided for children and young people in the formal system where the process of adapting school syllabuses to new trends in mathematics teaching is often slow. In this respect, out-of-school activities provide an excellent opportunity to introduce new ideas, stimulate young peoples’ interest in scientific and technical subjects by offering them the opportunity to develop their skills and talents in novel and entertaining ways.

**Activity Theory**

**Activity Theory in Mathematics Education**

Mathematics education is a field that is characterized by complexity. Mathematics in its historical development is interrelated with technology, other sciences, and culture. Teaching and learning processes have complex structures that involve differentiated conditions and factors in the social and cognitive development of students and teachers. As a reaction to this complexity in mathematics education, there is a need for a theoretical basis that allows us to better understand and identify the many aspects that inform mathematics education. The theoretical framework of Activity Theory (AT) will be presented to guide many aspects of this study. Activity Theory (AT) is a cross-disciplinary framework for understanding, analyzing and explaining different forms of human activity. AT has a focus on the subject, the object of the action and the tools used within the action. AT as a theoretical lens also focuses on the rules, division of labor and the community that guides and shapes the action and the outcome.

An activity is composed of a subject, who is a person or a group engaged in the activity, an object which is the objective, task or purpose of the activity, and tools. The object is seen and manipulated within the limitations set by the tools. The subject is motivated by the need to
transform the object into an outcome. The process is mediated by one or more tools. There is rarely a direct relationship between the subject and object - human activities are nearly always mediated by tools. The group impacted by, or influencing, action of such tools would be defined as the subject. The object of the action refers to the aim of an activity system that is reached through a subject using the mediating tools. Rules are the norms that guide and restrict the activity, the division of labor is the breakdown of power and tasks within an activity system, and the community is the social context in which the subjects belong. These three primary foci facilitate and constrain development of an action. Finally, the outcome describes the end result from investigating the activity system.

The purpose of utilizing AT is to draw on and extend sociocultural learning theory to develop a model of teacher mediation of activity to support student mathematical and technological understanding and self-efficacy. AT proposes both teaching and learning as a dynamic multi-level process that takes place as the individual interacts with the environment through a cultural lens (Vygotsky, 1978). An environment includes social interactions with others, objects and tools that one uses, and the contextual influence of the experiences. Vygotsky (1978) emphasized learning through teacher to pupil interactions. Although learning can occur for all interacting members, however, often an individual with a more advanced understanding of the concept guides others. Emphasis is on the cultural lens because one does not passively learn or accept all of the external influences, but interacts with experiences encountered.

Exploring technology can mediate this process, uncovering the beliefs and value systems they develop over time and examining how these beliefs and value systems of teachers thoughts on technology affect their experiences and are shaped by their school contexts (Roth, 2003). This study will adopt an activity lens to gain insights about the process of using technology as a
mediator for the self-efficacy and mathematical understanding students will acquire doing mathematical tasks that are contextually meaningful for urban high school students.

From a sociocultural perspective, the strength of using technologies or exploring real-life contexts lies in the support for collectively evaluating pupils’ ideas, and co-constructing new knowledge. The GIS technologies provide a dynamic and manipulable object of joint reference offering new forms of support for both teachers and students. These technologies potentially contribute to creation of shared space of communication. The technologies affordances of interactivity and ability to display multiple means of representation, offer new opportunities for students to express ideas, receive critical feedback from computer generated graphs and reformulate, both verbally and using other representations.

**Activity Theory Used in Understanding Interpretations of Graphs**

According to Roth (2003), graphing is a social practice that humans learn in relation with others; the relation is what is subsequently attributed to the mind. Because graphing is a social fact, it can be studied using activity theory as a framework. The sociology of science is deeply rooted in the importance of the interpretations of “graphical representations, which in the sociology of science and in postmodern discourse have come to be known as inscriptions, are central to scientific practice” (p. 2). However, understanding of the context of the construction of graphical inscriptions is vital to their interpretation. This is important in terms of the study as issues concerning the ways that math ideas are externalized, interpreted and communicated have received increasing attention, and this activity theory stance that the author has taken resonates with the word done in several fields in math education (Roth, 2003).

The goal of using AT for this study is to understand and explore individual consciousness (cognitive acts) rooted in the everyday practice of the students (Nardi, 1996). Artifacts here may
be either tools or symbol systems (e.g., languages). In this project, the point of reference is Nardi’s version of activity theory as applied to human computer interaction (HCI) research. Consequently, the examination of tool use in this context shifts to the structuring of activities. The modalities of employment are geared toward creating activities designed to encourage the engagement of all participants. In this case, the didactical functionalities are defined in terms of how the tools are used to structure the activities.

In one example, AT was used by K. Gutiérrez, Baquedano-Lopez, & Tejeda (1999) to examine zones of development that can occur in mathematics classrooms to accommodate productive activities by diverse sets of learners. In this study of afterschool programs there is a focus on reorganizing the roles, participation frameworks, and division of labor; in short, the social organization of learning in this setting results in new activities and outcomes. In another example, Wenger (1998) provides a theoretical framework that focuses on issues of practice and identity, and the relationships between them.

Drawing upon Wenger’s (1998) framework, Nasir (Nasir & Saxe, 2003) illustrates the ways in which individuals change as they engage in the practices of playing dominoes and basketball. Her analyses indicate that as individuals become more accomplished, their goals change; their relationships to the communities of practice (domino and basketball players) change; and their own definitions of self, relative to the practices change. Nasir illustrates the bidirectional character of relations between identity, learning, and goals.

Gordon (1995) examined student attitudes and expectations of statistics courses by analyzing student responses to interviews and surveys. Gordon used Activity Theory – a philosophical framework in which human activities can be explained by the subjects’ interaction with socially situated phenomena (Engeström, 1999) – as a lens to interpret the data, namely
positing that students’ perceptions, personal and societal goals, as well as their views on the relevance of statistics, influence their learning of the subject matter. More specifically, a student who sees statistics as a barrier to a chosen vocational path might not value being asked to strive for depth in understanding statistical notions.

By adopting activity theory as a framework, this study explicitly viewed the processes of mathematical understanding and self-efficacy as being informed by prior knowledge, cultural ideas, and constantly evolving with continuous interactions within multiple, complex contexts. AT moves beyond individual cognition to see classroom interactions – as a set of nested activities within an overall system meant to pursue educational outcomes (Kuutti, 1991).

Activity systems are composed of individual subjects (Teachers and students) each pursuing objects (Learning/performance goals related to activity). They make use of tools (tech). They collaborate with a specific set of rules or conventions that dictate the meaningful interactions – including division of labor. However, objects can be transformed in the course of an activity; they are not incontrovertible structures. According to Kuutti (1991) during the process of an activity, it is conceivable for the object to change. Objects do not, however, change on a moment-by-moment basis. There is some stability over time, and changes in objects are not trivial; they can change the nature of an activity fundamentally. Exploring the tensions between the objects and the technological tool over time can show a gradual shift in an individual’s mathematical understanding moment-by-moment. However, exploring and make meaning in and across activities and settings, subject to the norms and conventions of a community in terms of self-efficacy is a more difficult task. The components of activity systems are not static components existing in isolation from each other but are dynamic and continuously interact with the other components through which they define the activity system as a whole. From an activity
theory perspective, an examination of any phenomenon must consider the dynamics among all these components. In addition to the interactions of an activity system of a particular time and space, it is important to note that an activity system is made up of nested activities and actions, all of which could be conceived of as separate activity systems or other instances of the same system depending on one’s perspective (Barab, Barnett, Yamagata-Lynch, Squire, & Keating, 2002).

According to Van Lier (2005) using AT as a tool to explore behavior, cognition, and interaction can blur the boundaries of a case study. This vagueness can be problematic when identifying the boundaries of an activity system and ascertaining where the case study begins or ends. This uncertainty about boundaries is observed by Barab et al. (2002) who note that “an activity system is made up of nested activities and actions all of which could be conceived of as separate activity systems or other instances of the same system depending on one’s perspective” (p. 79). Data grouped within this category necessitate a nested system of activity (Yamagata-Lynch, 2003) where an outcome in a preceding learning activity (activity system) influences or is appropriated as a resource in another activity system.

**Self-Efficacy**

Self-efficacy has proven to be an important building block on the road to student success in mathematics. Self-efficacy has the potential to facilitate or hinder our mathematics learner’s motivation, understanding, and disposition to learn (Bandura, 1977). For the intent and purpose of this study, self-efficacy explains the judgments made and the potential to learn successfully and the belief in one’s own capabilities (Bandura, 1997). Self-efficacy impacts a learner’s potential to succeed (Bandura, 1977). An insight into the self-efficacy of learners is a valuable tool for creating successful learning environments (Bransford, 2000). It is important for
educators to know how students feel, think, and act, about, within, and toward mathematics. The influence of attitudes, values and personality characteristics on achievement outcomes and later participation in the learning of mathematics are important considerations for mathematics educators (Yates, 2002).

One way to gain insight into how learners feel, think, and act, about and toward mathematics is to examine the psychological domains of functioning: the affective, the cognitive, and the conative (Tanner & Jones, 2003). It is important to examine each domain, as a student may feel efficacious within the affective domain but less confident within the cognitive domain. Affect is a student’s internal belief system (Fennema, 1989). The affective domain includes students “beliefs about themselves and their capacity to learn mathematics; their self-esteem and their perceived status as learners, their beliefs about the nature of mathematical understanding; and subject” (Tanner & Jones, 2003, p. 277).

The cognitive domain involves students’ awareness of their own mathematical knowledge: their weaknesses and strengths as well and their development of links between concepts learned (Tanner & Jones, 2000). Cognition refers to the process of coming to know and understand; storing, processing, and retrieving information. The cognitive factor describes thinking processes and the use of knowledge. Conation refers to the act of striving, of focusing attention and energy, and purposeful actions. The conative domain includes students’ intentions and dispositions to learn, their approach to monitoring their own learning and self-assessment.

One research study increased students’ self-efficacy through a mastery experience intervention involving a goal manipulation (Luzzo, Hasper, Albert, Bibby, & Martinelli, 1999). They structured a number series completion task, introduced as a measure of math understanding, so that success was likely. Many of the student participants were told that the
minimum passing score was successful completion of six trials; the rest were not told. The “proximal goal” participants not only reported greater STEM self-efficacy compared to the control group immediately after the intervention, but they also reported greater STEM self-efficacy four weeks after the intervention. Luzzo et al.’s findings suggest that even minor, somewhat contrived interventions can have a significant impact on self-efficacy.

In another study, Dunlap (2005) assessed the effect of mastery experience on college students’ technology self-efficacy. Students were assigned a real-world problem and required to structure their solution by setting goals and creating action plans as they worked to solve the problem. During the study, students were continuously encouraged to incorporate new knowledge and skills and to reflect on their use of resources and strategies as well as their performance (i.e., self-regulation). At the end of the program, students reported significantly higher self-efficacy. An insight into the self-efficacy of learners is a valuable tool. Following, will be an explanation of the research base that exists on self-efficacy in terms of real-life meaningful contexts and technology in mathematics classrooms.

Self-Efficacy and Contextual Problems in Mathematics

Tasks that involve meaningful context for students have been deemed as an important factor that could improve attitude towards mathematics learning. One such meaningful learning experience was described by Donaldson (1978) where students saw both purpose and relevance in their learning. Meanwhile, Middleton and Spanias (1999) suggest real-life problem situations in mathematics instruction to uncover important and interesting knowledge, which can promote understanding. A major construct predicting mathematical understanding involves the affective domain of self-efficacy (Bandura, 1977, 1986) which includes students’ self-esteem and their
perceived status as learners; their beliefs about the nature of mathematical understanding (Eynde, deCorte, & Verschaffel, 2002; Tait–McCutcheon, 2008).

**Self-Efficacy in Mathematics and Technology**

In terms of technology, the social cognitive perspective of self-regulated learning suggests that effective learning is also determined by the interactions among affective, cognitive, and conative influences; particularly, high self-regulated learners hold higher motivation (affective), apply better learning strategies (cognitive) and respond to environmental demand more appropriately (conative).

With a large percentage of urban students from low-income families attend schools that are underfunded, exploring a research base in the instruction of urban students will be necessary across the country (U.S. Department of Education, 2010). Access to instructional technologies for these students needs to increase in order to ensure their participation in the technology skills necessary in the 21st Century. Depending on school location, students have different access to technology. Students who attend urban schools are less likely to have access to computing technology at home and school (Wenglinsky, 1999). Urban schools that have predominantly minority students have used computers for drill and practice. As a result, there is concern that this differing access to technologies will widen achievement gap between low and high students’ achievement which can cause a technological underclass in schools (Becker, 2000).

As noted above, the effects of personal beliefs about learning have been the topic of investigation in educational settings, but have rarely been studied in the context of technological learning (Tobias, 2006). Some researchers, however, suggest that motivation is even more important in the Internet environment than a more traditional classroom (Tobias, 2006). For example, research suggests that motivation is the most important student attribute significantly
related to educational performance with the use of technology (Sankaran & Bui, 2001).
Specifically, research suggests that self-efficacy or students’ beliefs regarding their capability to
eexecute actions necessary to achieve designated outcomes (Bandura, 1986), has a stronger effect
on academic performance than other motivational beliefs (Pintrich & DeGroot, 1990; Pintrich &
Schunk, 2002). Self-efficacy also has been found to have critical effects on various types of
academic learning (Bandura, 1996, 1997, 2000; Pintrich & Schunk, 2002). Studies have shown
that self-efficacy is strongly related to learning with technology and performance (Pintrich &
DeGroot, 1990). For example, research demonstrates that students’ self-efficacy in using the
internet significantly impacts achievement (Pintrich & Schunk, 2002).

Connection Between Self-Efficacy and Understanding

A relatively new track of educational inquiry would be the application of Bandura’s
(1977) self-efficacy theory to understand behavior, more recently the behaviors of urban high-
school students. According to Bandura (1977, 1986), to help increase access to educational
options for a growing yet underrepresented population, we need to increase our understanding of
important factors in their educational development. There exists enough evidence to highlight the
importance of the relationship between students’ successful learning experiences and their
expressed interests. Self-Efficacy (SE) beliefs constitute a key component in Bandura’s social
cognitive theory. The construct signifies a person’s beliefs, concerning her or his ability to
successfully perform a given task or behavior. SE is a major determinant of the choices that
individuals make, the effort they expend, the perseverance they exert in the face of difficulties,
and the thought patterns and emotional reactions they experience (Bandura, 1986). Furthermore,
SE beliefs play an essential role in achievement motivation, interact with self-regulated learning
processes, and mediate academic achievement.
Bandura (1986) argues that SE refers to personal judgments of one’s capabilities to organize and execute courses of action to attain specific goals, and that measuring SE should focus on the level, generality and strength across specific activities and contexts. Therefore, whereas a subject-specific self-concept test item might require the respondent to react to the statement “I am a good student in Mathematics”, the SE item would require reaction to the statement “I can solve percent problems.” Ignoring this tenet leads to insufficient research findings, and that is why Pajares (1996) argues that if the purpose of a study is to find relationships between SE and performance, SE judgments should be consistent with and tailored to the domain of the task under investigation.

Bandura (1986) claims that young students are generally overconfident about their abilities. However, attention is needed for the protection of children from the danger of disappointment, in the case of continual failures. Children’s SE beliefs become more accurate and stable over time, and it is very difficult to change them (Bandura, 1997).

**Mathematical Understanding**

Graphical representations play an important role in mathematics education by summarizing complex information or relationships effectively. Although graphs are explicitly taught in mathematics classrooms, many subject areas such as science or social studies utilize graphs to represent and interpret relationships. The ability to interpret or construct graphical representations is a crucial skill for all students, whether or not they want to pursue mathematics-related careers. However, researchers have detected that many students lack graphing skill (Dunham & Osborne, 1991; Goldberg & Anderson, 1989; Ozgun-Koca, 2001).

Although national standards indicate the importance of using graphs to develop an understanding of modeling in mathematics classrooms, many other subjects such as science or
social studies also utilize graphs to represent and interpret relationships. Depth and breadth of understanding are characterized by the ability to recognize the implications of the information at hand and to put it into a broader context; and by the ability to draw upon different disciplines to provide a clearer and deeper understanding of the discipline with which the student is immediately concerned. Although, students often have problems with graphing and modeling data collected from real-life sources (P.H. Dunham & T.P. Dick, 1994), researchers agree that studying graphs can lead to a deeper understanding of physical phenomenon through data (Dunham & Osborne, 1991; Goldberg & Anderson, 1989). Despite these issues with graphical interpretations, little research has explored mathematical problems that invoke a meaningful context for students in urban areas.

**Real-World Tasks and Mathematical Understanding**

The CCSSM suggest that modeling as a vital feature of the mathematics curriculum may provide ways to help students make sense of the content and at the same time contribute to their understanding of the concepts they are studying.

“Modeling is the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions… As no bulleted list of specific content standards will hold together as a coherent, meaningful whole, or make any significant contribution to our students’ growth in mathematics, without interweaving mathematical “practices.” (Council of Chief State School Officers, 2010, p. 72).

Besides showing students how mathematics is related to the real world it also serves to increase interest in the subject matter. In a study of using graphing calculators to solve real-world problems, Bowman (1997) stated that after allowing his students to work with real-world problems, the level of student interest increased to the extent that “they were especially excited
about being able to solve a mathematics problem that even the so-called ‘math geniuses’ in calculus could not solve (p. 2).

Mathematics curricula must show students the power of reasoning and sense making as they explore mathematical structures, communicate as they construct viable arguments, and demonstrate understanding through multiple representations as they engage in mathematical modeling.

**Connecting graphical understanding with the real-world.** Students tend to have difficulties differentiating between graphs that are presented to them and the real world structures that they represent (Dunham & Osborne, 1991; Lapp & Cyrus, 2000; McDermott, Rosenquist, & Zee, 1987). One common misconception that hinders students’ understanding of graphical representations of data is graph-as-a-picture confusion, wherein students do not see a graph as a relationship between variables but rather as one object (Dunham & Osborne, 1991; McDermott, et al., 1987; Mokros & Tinker, 1987). Students often believe that the shape of the graph should resemble the shape of a physical object or setup of the experiment. Using graphs to explain a real world phenomenon is a vital skill in mathematics and science, allowing them to leap back and forth between a graph and the phenomenon that the graph describes. According to McDermott (1987), in order for students to connect graphs with physical concepts, they need to see a variety of graphs representing different physical events. Students' understanding of mathematical ideas can be built through actively engaging in tasks and experiences designed to deepen and connect their knowledge. Understanding can be further enhanced through real-life examples where students can propose mathematical ideas that assist them in developing mathematical reasoning skills (Bransford, Brown, & Cocking, 2000).
Beckett et al. (2005) assert that an urban planning simulation using new technology informed by real-world urban planning practices and tools “may be a productive platform for developing students’ understanding of the ecological domain” (p.32). This study examined whether and how participation in a complex urban planning simulation in the context of real world tools and practices informed student understanding of real life ecology issues. They believed that one approach to creating stronger connections between students’ experience of the real world and students’ actions in a virtual model of a complex ecological system is to link real and virtual elements. Creating graphed simulations, the students are explicitly guided by real-world tools and practices such as the use of technologies used by professionals in urban planning.

Cognition is situated in the fullest sense, challenging the notion of abstracted skills in mathematics and other disciplines. "Without the meaningful totality into which each sign can be connected through the production of interpretants, [this] kind of reasoning with population graphs or supply-demand curves is impossible. (p. 60).

In one study, Coltman, Petyaeva and Anghileri (2004) realized that introduction of meaningful context led to improvement in post test results as compared to those of the pretest. It was also reported that these students yielded results that were better with the use of a meaningful task but also with guided feedback from an adult. This feedback created opportunities for change and thus allowed success while carrying out students tasks. In another study involving academically at-risk students, it was noted that to succeed in mathematics, a balance between sufficient opportunities for success and tasks that require considerable effort was imperative (Woodward & Brown, 2006). Therefore, students might need to experience periodic challenges and even momentary failures to develop higher levels of self-efficacy and task persistence (Bandura, 1986; Middleton & Spanias, 1999).
When examining the use of real-world problems to improve student understanding of mathematical proof, Hodgson & Riley (2001) state that their experiences show that real-world problems supply an important aspect missing from typical classroom instruction. When mathematics is to be related to reality, not only is reference being made to real-world problems but also to the fact that the mathematics must make sense to students. It must remain as close as possible to the concepts that students already have and know. The work they do must appeal to them within the frames of reference that they understand. Selden & Selden (1999) state that:

> From the perspective of realistic mathematics education, students learn mathematics by mathematizing the subject matter through examining 'realistic' situations, i.e., experientially real contexts for students that draw on their current mathematical understandings. (p. 9)

Besides working on meaningful tasks and being given relevant feedback, research has shown that low achieving students who were taught in an active classroom—one that provided students with opportunities in problem solving using real life scenarios and active classroom discussion, achieved higher academic outcomes and had more positive attitudes towards mathematics than students in the comparison group (Woodward & Brown, 2006).

Exploring how using real-world problems in Science and how that specifically influences urban students, Roth & Barton in *Rethinking Scientific Literacy* (2004) found that being literate in the data available from the media as those who are not data literate do ... “

> not account for the fundamental relationships between individual and society, knowledge and power, or science, economics, and politics ... [Data] must be understood as community practice, undergirded by a collective responsibility and a social consciousness with respect to the issues that threaten our planet. (p. 3)

Roth (2004) explores one case of students using technology and data to solve real-world meaningful problems. These students explore a creek that has been compromised over a long period of time. Environmental activists and the town council are struggling with issues associated with renewing the stream. Students become involved in research on the creek, along
with scientific specialists. From there, data sources include deliberations in town council meetings where all community members participate. A major theme that emerges from this research has to do with genuine involvement of students in a 'real' socio-scientific problem setting.

Another case concentrates on transforming a garbage-strewn vacant lot into a safe and useable community playground. What is most noteworthy is that the teenagers gradually came to believe that they were active agents in making a difference in their circumstances - despite their own urban living stations and restrictive home environments. This case has many implications for student learning. First, if learning that has a purpose to students, then they own that purpose absolutely. Secondly, the students had decided to do something that has obvious, real payoff. In fact, one young person to contrast the project with what he saw as typical 'fake' projects in his school science experience (p. 96).

Roth and Barton (2004) indicate that there is an importance for students to be involved in real-world problem solving as these types of activities [are] ... designed to empower students to deal with [STEM] and scientific experts on emerging socio-scientific issues" so that "students have to play the roles of scientists, environmental activists, or local residents in a pretend activity" (p. 176).

**Technology and Mathematical Understanding**

The NCTM (2000a) determined that effective use of technological tools might assist students in communicating their understanding of mathematics they are learning while engaging in mathematical tasks that require them to graph, visualize, and compute. This growing trend of encouraging students to harness the power of technology to improve their mathematical understanding has been accompanied by a concern among teachers and mathematics educators
about the challenges involved in utilizing technology in the mathematics classroom. However, there have been relatively minimal efforts to identify key issues that would inform understanding about the pedagogical effect of using technology in mathematics teaching (Chinnappan & Thomas, 2000; Lesh, 2000). Chinnappan & Thomas (2000) explored students understanding of functions through mathematical modeling of real-world problems with educational technologies. They found that using real-world examples allowed students the freedom to use previous concepts and apply them in a meaningful way while still addressing the mathematical concept at hand. The teacher acted as the facilitator transitioning students from the different representations of a function and guiding them to discover the various impacts of the values in the equation they had created. Chinnappan et al. (2000) maintain that technology can introduce new norms for mathematical arguments, radically expand the kinds of successful mathematical understanding available, and encourage representational fluency in the understanding of mathematical constructs. Also, NCTM advocates that effective use of technology should foster environments where students are encouraged to analyze and interpret graphical information. The “freedom to explore, conjecture, validate and convince others is critical to the development of mathematical reasoning... (and) reasoning is fundamental to the knowing and doing of mathematics” (NCTM, 1989, p. 81).

Over the past several decades, scholars have stressed the importance of using technology as an integral step toward positive school reform (Bruder, Buchsbaum, Hill, & Orlando, 1992; Campoy, 1992). In fact, the Technology Principle for the NCTM states that "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (NCTM, 2000a, p. 24). As a result, federal funding has been directed toward purchasing new technologies in order to prepare students for the 21st Century
However, to date, educational technologies have been “oversold and underused” and have only made minor impacts in the quality of instruction and student understanding in mathematics classrooms due to teacher discomfort with technology and the lack of professional development to assist with properly incorporating technology in the curriculum (Collins & Halverson, 2009; Cuban, 2001).

The National Council of Teachers of Mathematics (NCTM) identified the "Technology Principle" as one of six principles of high quality mathematics education in the Principles and Standards of School Mathematics (NCTM, 2000b). This principle states: "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (p. 24). In support of this principle, research has shown that the use of educational technologies brings about enhanced student understanding in mathematics by incorporating an array of technological activities that engage students in mathematical thinking facilitated by technological tools (Pea, 2004).

In a discussion about “new technologies” in classrooms, Cuban (2001) asserts that "[c]omputers have been oversold and underused, at least for now," (p. 179). New technologies, according to Cuban, include both hard and soft infrastructure such as computers, presentation software, cameras, technical support, and professional development. Cuban continues that a more recent area of reform in schools is pushing toward the use of new technologies in classrooms. Many believe that this type of reform may be a way to revolutionize teaching and learning in that it would move away from teacher-centered instruction and encourage collaboration and discussion, student-led projects, and student-centered environments. Many proponents of school reform through new technologies share the belief that once these technologies are present in the classroom, they will be instrumental in transforming educational
practices. However, if we consider their impact on the student life within the average American classroom, computers have failed to deliver the transformation in learning that has been promised and promoted over the past fifteen years.

Technology has been seen as a panacea to improve education. As a result, many schools are acquiring technology, but there has been little work to help teachers learn to use these tools to promote student learning. In addition, there is little empirical research on the effects of technology in the classroom; most of the literature either extols the virtues of technology or provides information about how to set up and use specific technologies (Cuban, 2001; McCrummen, 2010). Classroom technology is the tool conveying the instruction and not the instruction itself. There needs to be further research into how technologies (including GIS and Excel) can be utilized in mathematics classrooms to promote a more positive disposition toward using technology as a tool for teaching and enhancing instruction, which might in turn increase student engagement and performance.

According to NCTM, technology fosters environments where students are encouraged to analyze and interpret graphical information. The "freedom to explore, conjecture, validate and convince others is critical to the development of mathematical reasoning... (and) reasoning is fundamental to the knowing and doing of mathematics" (NCTM, 1989, p. 81).

According to Shaffer (2004), new technologies make it possible for students to participate in meaningful learning activities by serving as a bridge between professional practices and the needs of learners. Mokros and Tinker (1987) studied the effects of technology in students’ understandings about graphing. The use of technology allows students to collect real-time physical data – such as temperature, motion, light, or sound – which can later be transferred into a computer or a calculator to be studied through a variety of representations such as graphs
or tables. They conclude that “…in a three-month longitudinal study using these technologies, students showed a significant gain in understanding of graphing” (Mokros & Tinker, 1987).

To date, the most popular technology used in urban planning is geographic information systems (GIS). GIS models make it possible for planners to explore multiple potential solutions to problems, and to obtain feedback that informs decision-making processes (Beckett & Shaffer, 2005). In these ways, GIS models support and provide access to the practices of urban planners. Likewise, Dugdale (1993) claims the potential for graphing software, to enhance students’ understanding of functional and graphical relationships, arguing that interpretation of graphs must go beyond plotting and reading points. In terms of urban planning, students learn to set up a simple spreadsheet and use it in posing and solving problems, examining data, and investigating patterns, can be helpful in the interpretation of graphical data that can be collected from GIS technology for urban planning (Beckett & Shaffer, 2005). Which relates to students understanding of graphical interpretations by affording access to technology to assist with activities that can incorporate multiple representations of mathematical topics? Historically, scientists and educators have used computational and visualization technologies to investigate and explore complex systems and phenomena. Within the last decade, tools that practicing scientists have used to build computational models intended to visualize complex concepts and phenomena have been harnessed to assist students learning science and mathematics (Edelson, Gordin, & Pea, 1999; NSF Task Force on Cyberlearning, 2008). This is due, in part, to the fact that educators have recognized that visualizing data can facilitate the development of mathematical-scientific understanding of the natural world (Kim, et al., 2007). Further, the growing power of computers, coupled with a reduction in cost and the availability of increasing sophisticated software, has created opportunities to engage students in scientific inquiry through
visualization and simulation of mathematical phenomena (Vogel, et al., 2006). Research shows that technology can be effective in helping students make such connections.

According to the National Council of Teachers of Mathematics (NCTM) (1989), “[c]ommunication with and about mathematics and mathematical reasoning should permeate the … curriculum” (p. 66). Although researchers agree that studying graphs can lead to a deeper understanding of physical phenomenon through data (Dunham & Osborne, 1991; Goldberg & Anderson, 1989), students often have problems with graphing and modeling data collected from real-life sources (P.H. Dunham & T.P. Dick, 1994). Specifically, in one study, Dede (2009) explores how immersion in technologies that invokes realistic experiences, can enhance education in at least three ways: by allowing multiple perspectives, understanding concepts, and transferring to other content areas.

This growing trend towards helping students harness the power of technology for improving their mathematical understanding has also been accompanied by a concern among teachers and mathematics educators about the problems and issues involved in employing technology in the mathematics classroom (Collins & Halverson, 2009; Cuban, 2001). However, there has been relatively little attempt to identify key issues, which would inform current levels of understanding about the pedagogical effect of using technology in mathematics teaching (Chinnappan & Thomas, 2000; Collins & Halverson, 2009; Lesh, 2000). Nor has there been a coherent exposition of what research has to say about the cognitive effects of technology on students' mathematical understanding. Lesh (2000) maintains that technology can introduce new norms for mathematical argument, radically expand the kinds of successful mathematical understanding available, and encourage representational fluency in the understanding of mathematical constructs.
An important theme to emerge from educational technology research is that technology has the potential to support higher levels of mathematics understanding; we need to be constantly aware of human-machine and human-human interactions. Mathematics learning within a technology-based environment needs to consider the complex interaction between the properties of the tool and students' and teachers' cognitive characteristics. Numerous studies document student understanding of mathematics concepts from using computer-based and assisted software (Dugdale, 1993; Guerrero, Walker, & Dugdale, 2004; Lapp & Cyrus, 2000). In one study by Lapp & Cyrus (2000), students used a calculator-based technology to collect data about their distance from a motion detector and to generate a distance-time graph in real time. During the activity, the students initially did not understand the distance information that the given graph was conveying. However, as a result of the intervention, students left this program with the ability to understand how technology can help provide a link between the data collected and the graphs created. Algebra and geometry software, interactive presentation devices and software are among those effective in facilitating mathematics achievement for elementary, middle, and high school students when teachers are skilled in guiding student activities (Glover & Miller, 2001; Hillel, Kieran, & Gurtner, 1989; McCoy, 1996).

Spread-sheets and graphing software include tools for organizing, representing, and comparing data. This activity illustrates how weather data can be collected and examined using these tools. Mokros & Tinker (1987) studied the effects of technology in students’ understandings about graphing. The use of technology allows student to collect real-time physical data such as temperature, motion, light, or sound. These data can then be transferred into a computer or a calculator to be studied through a variety of representations such as graphs or tables. It was concluded in this article that “...in a three-month longitudinal study using these
technologies, students showed a significant gain in understanding of graphing (Mokros & Tinker, 1987). Dugdale (1993) discusses potential for graphing software to enhance students’ understanding of functional and graphical relationships. She argues that interpretation of graphs must go beyond plotting and reading points. In terms of urban planning, this could involve students learning to create a simple spread sheet and use it to pose and solving problems, examine data, and investigate patterns, can be helpful in the interpretation of graphical data that can be collected from GIS technology for urban planning (Beckett & Shaffer, 2005).

The literature sheds light on the importance of mathematical understanding for student success in mathematics. Findings indicated that the use of technologies can bring a more real-world connection for students learning mathematics. Studies also addressed how these real-world connections can enhance student’s interest in the subject learned. Some of the research connected student’s perceptions and practices of using technologies in mathematics classrooms to pupil mathematical learning; however, researching these real-world mathematical problems was rarely examined empirically with the goal of exploring urban students. Overall, the research presented valuable insights into the process of using technology to learn mathematics.

**Conclusion**

Mathematics education has undergone several changes over the past fifty years and national standards have been at the forefront of major reform efforts (Council of Chief State School Officers, 2010; NCTM, 2009). Through the efforts of several mathematics educational leaders, researchers, and teachers, mathematics education has made a great deal of progress; however, much work is needed to increase collaboration across the nation and to improve policies and practices that support these efforts. Furthermore, at the local level, much needs to be learned about how to advance the teaching and learning of mathematics for all students. Having
students doing meaningful, contextual tasks as well as using technology as a mediating factor for the learning of mathematics align with these new standards.

The research on self-efficacy related to mathematics confirms the task-specific nature of self-efficacy (Pintrich & Schunk, 2002), and establishes self-efficacy as a key element of self-regulation (Bandura, 1997). Mathematics self-efficacy is positively related to academic performance, persistence, and math-related career choices but intervention efforts have thus far not proved successful (Schunk & Gunn, 1986).

The research on mathematical understanding indicates the importance of self-efficacy in the beginning stages of mathematical understanding (Pintrich & DeGroot, 1990). However, in order to engage students and have them involved in the process of doing mathematics, it is important to provide situations where students can solve real-life problems that are contextually meaningful to them (Mokros & Tinker, 1987). As the literature also shows, the use of technology can assist with mediating the learning of these real-life problems (Beckett & Shaffer, 2005; Shaffer, 2004).

These bodies of literature paint a picture of the many factors that can lead to an increased understanding of mathematical concepts. Mathematical self-efficacy plays an important role in learning mathematics (Dunlap, 2005) and mediates the influence of both motivation and interest of learning environments on understanding mathematical concepts (Eynde, et al., 2002; Tait–McCutcheon, 2008).

In order for mathematics to be of interest to students it must make sense (Bowman, 1997). It must remain as close as possible to the concepts that children already have and know. The work they do must appeal to them within the frames of reference that they understand (Bransford, et al., 2000). Creating real-world problems for students to solve gives students the interest and
motivation to become successful in the mathematical tasks given to them (Bowman, 1997). Many issues in day-to-day life can be modeled by different types of technologies.

According to the NCTM Technology Principle "technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (p.24). To structure these technologically rich learning environments, the primary focus should be to support mathematical understanding (Lapp & Cyrus, 2000). As mentioned in Beckett et al. (2005) creating real-world computer simulations that mimic how professionals use technology is a platform that should be used to developing students’ understanding of solving real-world problems. However, little is known either about the influence of how technologically mediated, real-world problems can influence urban students’ self-efficacy or whether math self-efficacy mediates the influence of these technologically rich learning environments on mathematical understanding. What follows is a description of this study and how real-world, contextualized mathematical texts that are mediated by professional technologies may influence students’ mathematical understanding and self-efficacy.
Chapter 3

METHODOLOGY

The over-arching question driving this study is “How does involving SSJY high school students in real-world, meaningful mathematical urban planning projects in their own neighborhoods influence their mathematical understanding of graphical representations?” The exploration of this question was also examined through sub questions examining how the students’ self-efficacy and mathematical understanding of interpreting graphical representations was influenced by the use of professional urban planning technologies. Given that very little is known about student understanding of mathematics content facilitated by GIS (DeBay, et al., 2012), the goal of this research is to examine how these real-life, technologically rich, urban planning explorations influenced the self-efficacy and mathematical understanding of graphical interpretations for urban students.

This study used a mixed-methods methodology to reveal the intricate interrelationships between meaningful, contextual problems and the assistance of urban planning technologies are necessary for a complete understanding of this activity (Teddlie & Tashakkori, 2003). The National Research Council (2002) claims that research designs can be strengthened by using multiple methods that integrate “quantitative estimates of population characteristics and qualitative studies of localized context” (p. 108). Quantitative research was used in this study to find potentially significant differences in mathematical understanding and self-efficacy. Then, these significant themes will be explored using a qualitative research approach. This qualitative case study is principally suited to this project as, “it consists of a set of interpretive, material practices to make the world visible” (Denzin & Lincoln, 2000, p. 3). As such, these methods are of value for “refining theory and suggesting complexities for further investigation” (Stake, 2000,
investigations that will be necessary to expand the knowledge base on this important topic.

As conveyed in the problem statement of this study, mathematical understanding in secondary mathematics and, more specifically, graphical interpretations of data, occurs in far too few urban classrooms. The inclusion of meaningfully mathematical tasks mediated by professional technologies recorded promise to inform efforts to ensure that effective mathematics education is more widely available to all students. Chapter 3 defines the research process to answer the research questions and produce findings.

For rigorous research, appropriate research design and methodology is necessary to successfully answer the research question (National Research Council, 2002). Following is a description of the study and explanations concerning why the chosen investigation is appropriate. The following sections will be covered: (a) research design, (b) participants and context, (c) data collection, (d) data analysis, and (e) the study’s limitations.

**Research Design**

Research has shown that mixed-method design is valuable for capturing both the depth and breadth of data (Creswell, 2003). To thoroughly investigate the research questions, the surveys, interview and observation protocols as well as final project artifacts were used in this study to connect to the problem.

For this project, Activity Theory (AT) was used as a lens through which the ways students developed mathematical self-efficacy and understanding was examined. In AT the construct that drives change in a system are the tensions between the vertices in that triangle (i.e. a tension emerges between the tool and the subject, etc.). As a result, AT was used to examine how students' development of self-efficacy toward mathematics disrupts the system, causing
tension. The goal is that this tension leads to better use of the tool to generate and interpret graphical data. The analysis of the qualitative and qualitative data through an activity theory lens allowed for the opportunity to characterize a holistic view of student learning in this real-world, technologically driven learning environment.

**Quantitative Methods**

The quantitative phase of this study consists of surveys and analyses of student self-efficacy and mathematical understanding of students interpreting graphical visualizations of data. The pre- and post-surveys were administered to all students involved in the urban planning project for the SSJY (See Appendix ?).

The survey given to students consisted of four subgroups. The first subgroup involved demographic data from students including name, gender and length of time in the SSJY program. The second subgroup involves five questions taken from posted National Assessment of Educational Progress (NAEP) assessments that explore students understanding of graphical data (U.S. Department of Education, 2010). The third subgroup involved nine items about students’ self-efficacy of general mathematics, followed by eight items more specifically about interpreting graphs and the last section involves ten questions exploring technological self-efficacy of the CommunityViz software. The final subgroup involves eight Likert scale questions exploring technological self-efficacy adapted from (Baalen, Dalen, Smit, & Veenhof, 2011; Compeau & Higgins, 1995).

Although these quantitative methods provide descriptions about students’ self-efficacy and mathematical understanding, it is important to capture a more in-depth picture of these elements through qualitative methods to better understand the process of students learning about interpreting graphs in real-life mathematical tasks.
**Qualitative Methods**

This project incorporated a bounded case study to analyze the data collected by following a group of 10 out of a possible 62 students throughout the course of the SSJY 2011-2012 year. According to Creswell (2003), case study research is a qualitative approach in which the investigator explores multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information (for example, observations, interviews and documents), and reports a case description and multiple case-based themes. Cohen et al. (2000) state that a multiple case study is a specific instance that is frequently designed to illustrate a more general principle. As a result, choosing to use a case study method will shift the focus to an instance throughout the activity (Cohen et al., 2000). Specifically, a bounded case study is a model for providing comprehension into the larger questions of both self-efficacy and mathematical understanding than a single case, as studying multiple cases in depth and comparing similarities and differences may help to provide representation to this larger issue (Stake, 1995).

This project was evaluative of a specific instance in activity, as it is investigating ten students’ usage of GIS and Excel to create and interpret graphs for urban planning; therefore through this investigation, decisions will be taken based on the findings (Patton, 2002). Interviewing students in different subgroups of interest across the target population is a way to understand the phenomenon in context-specific settings, such as a “real world setting [where] the researcher does not attempt to manipulate the phenomenon of interest” (Patton, 2001, p. 39), then more informed decisions can be taken that will contribute to the improvement of students graphical understanding.
All students will be targeted for participation in the study, as “selection by sampling of attributes should not be the highest priority. Balance and variety are important; opportunity to learn is of primary importance” (Stake, 2000). Given that qualitative research involves an interpretive naturalistic approach to the world, exploring the naturally occurring context of secondary students in an informal learning environment is considered an important opportunity to learn about these collective cases.

Access and Entry

Permission to conduct research with human subjects was pursued through Boston College’s Institutional Review Board. Consent was obtained from every participant. The Principle Investigator of the larger study allowed this study to occur under his directions, granting verbal permission.

Participants and Contexts

Participants

The students that participated in this study were involved in an afterschool Social Justice and Youth Leadership program (SSJY) that incorporates Science, Technology, Engineering and Mathematics (STEM). Research indicated that urban students are not choosing to major in STEM fields nor pursue STEM careers (Blustein et al., 2012). The program combines college preparation, career discernment and innovative technology efforts into a full year SSJY experience. One of the goals of the program is to expand the capacity for SSJY high school students to enter college prepared to focus on a STEM area and/or possess the transferrable STEM skills to pursue a variety of other careers such as law, psychology, media and education. The program, throughout the course of this study, involved 62 youth who regularly attended
sessions. Tables 3.1 and 3.2 present the demographics data for the 62 students participating in this study.

Table 3.1

**Gender Distribution of Students**

<table>
<thead>
<tr>
<th>Gender Distribution</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>38</td>
<td>61.29</td>
</tr>
<tr>
<td>Male</td>
<td>24</td>
<td>38.71</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3.2

**Racial Distribution of Students**

<table>
<thead>
<tr>
<th>Racial/Ethnic Distribution</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hispanic or Latino</td>
<td>21</td>
<td>33.87</td>
</tr>
<tr>
<td>Black/Afro-Caribbean</td>
<td>16</td>
<td>25.81</td>
</tr>
<tr>
<td>Black/African American</td>
<td>10</td>
<td>16.13</td>
</tr>
<tr>
<td>African American &amp; Afro-Caribbean</td>
<td>4</td>
<td>6.45</td>
</tr>
<tr>
<td>Black &amp; Hispanic/Latino</td>
<td>3</td>
<td>4.84</td>
</tr>
<tr>
<td>African American &amp; White</td>
<td>3</td>
<td>4.84</td>
</tr>
<tr>
<td>Black, White &amp; Asian</td>
<td>2</td>
<td>3.23</td>
</tr>
<tr>
<td>Asian/Asian American</td>
<td>2</td>
<td>3.23</td>
</tr>
<tr>
<td>White &amp; Hispanic/Latino</td>
<td>1</td>
<td>1.61</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>100</td>
</tr>
</tbody>
</table>

**Constructs**

The framework for understanding is based on the assumption that knowledge is represented internally, and that these internal representations are then explained externally by the student (Hiebert, et al., 1997). Between pre-post survey, interviews and observations, the goal of this study is to observe if these internal representations are effectively explained externally by the students. The literature reviewed has indicated that a technological intervention will positively affect students’ understanding and self-efficacy of interpreting graphs. The
independent, constant construct for this research project is a technological graphing intervention as all individuals will be receiving identical training, which might have a positive impact on the dependent variable constructs of student mathematical self-efficacy and understanding. The assumption is that students will experience different changes in understanding depending on how involved they are in the intervention. A potential confounding construct to be cognizant of is the use of technology. There has been little empirical evidence to show whether or not technology itself has an effect on student learning outcomes (Cuban, 2001), and if there is a relationship with technology, it will be important to differentiate whether the increased understanding is from the intervention or through the technology.

**SSJY Program Context**

The informal STEM program, Students for Social Justice (SSJY) is an intervention with the intention of working with underserved urban youth. SSJY is part of a larger, NSF-funded project aimed at examining long-term STEM interest and career development. Students typically participated in the program from 9th through 12th grade and were recruited primarily from 3 urban partner schools. These schools have a relationship with the university and many of the teachers in the SSJY program work within these schools. The students who were recruited for the program were largely average academic performers and recommended by their teachers. The students were generally not interested in STEM when they enrolled in the program, however drawn to the program for assistance with college preparation or the youth participatory action research program where students were provided with opportunities to discuss social justice issues within their neighborhoods. Students eventually developed the science and research skills needed to research the environmental and social justice problems and devise action plans which they reported back to their peers and community members.
For this project, SSJY students used urban development as the research problem, the students adopted vacant lots in their neighborhoods with the goal of re-designing these spaces to benefit their communities. The students visited the sites several times collecting physical scientific data such as temperature, sound levels, traffic counts and soil lead levels. Next, the students analyzed the data in order to develop a better understanding of the specific plot of land. With this data, the students generated 3-D surface plots in Microsoft Excel and analyzed the data in relation to the sites and identified factors that contributed to peaks in the air and ground temperature and the noise levels.

Following the field study and graphical analysis, the students learned to use a GIS technology called CommunityViz in order to lay out their urban development plans for the sites and used the software to further analyze the impacts of their design decisions. CommunityViz planning software is an extension for ArcGIS. Planners use CommunityViz to help them make decisions about development, land use, transportation, conservation and more. A GIS-based decision-support tool, CommunityViz shows you the implications of different plans and choices. The program supports scenario planning, sketch planning, 3-D visualization, suitability analysis, impact assessment, growth modeling and other popular techniques. Its many layers of functionality make it useful for a wide range of skill levels and applications. After the field survey of the site and graphical analysis, the students used CommunityViz to assist with making decisions about developing the parcels of land based on their new research knowledge of the site. They were able to assign various kinds of businesses, residences, recreation, surface materials, trees and foliage, signage and other aesthetics to the site. In the urban planning software, with every design decision, the program automatically generated graphical output data for a number of variables, for e.g. commercial and residential energy use, commercial and residential water
consumption, percentage of impervious surfaces, jobs generation, surface area and project site costs. The students had data, in terms of these variables, for the site as it was at that time before development, as well as two alternative designs, one residential and one commercial (as well as the design that they created). The students then argued the value of their designs based on the graphical results and the scientific understanding underlying their design decisions. At the end of each project site design, the students presented their projects. The students were expected to be able to communicate their urban planning decisions and experiences competently to their peers and instructors.

**Data Collection**

Data was collected from one of three classes comprised of approximately 62 students over the two years. Classroom activities and final presentations were digitally recorded and meaningful interactions transcribed and analyzed further. The quantitative portion of this study consisted of surveys and analyses of student work. The pre- and post-surveys were administered to all students involved in the SSJY program. The survey examined students’ mathematical understanding and self-efficacy of graphical interpretations and the use of GIS technology for urban planning. The survey involved a mixture of multiple-choice, Likert and open response items. First, a descriptive analysis was conducted to compare students’ quantitative responses. Second, students who changed their responses were identified and their open-ended responses further analyzed with the goal of determining a difference in understanding regarding interpretation of graphical data and the use of the GIS technology.

The data was collected from pre/post surveys, semi-structural interviews, video of lessons and final presentations. The pre-survey was given to students before the technological intervention and the post-survey given after the intervention was implemented. First, the pre-
survey asked students questions about their understanding of graphical representations of data and technology use were administered to 62 students prior to the study. The intervention included the learning tools integrated technologies prepared by the researchers. Furthermore, these representations involved integrated technologies such as Microsoft Excel ©, Geospatial Information Systems (GIS) technology, and Microsoft PowerPoint © presentations. After the pre-survey, the lessons and final presentations were videotaped as well as audio interviews. Finally, the post-interview was carried out with the students. All qualitative data was transcribed at the end of the study.

To explore these changes, the pre- and post- surveys were examined in two ways. First, a descriptive analysis was conducted to compare students’ quantitative responses. Second, students who changed their responses are identified and their open-ended responses are further analyzed with the goal of determining a difference in understanding regarding interpretation of graphical data. Ten students will be chosen after the pre-survey based on their understanding of interpreting graphs and technology usage in three different levels. Level One consisted of students who were able to interpret graphs at a limited level. Level Two students knew some interpretations of graphing and Level Three students were those who were able to functionally interpret graphs.

Instrumentation

**Surveys.** In studying the students’ overall mathematical understanding and self-efficacy of graphical interpretations, of the 62 students involved in the SSJY program 57 students completed both of the pre and post survey in order to gain information on student understanding. From the pre-test a multiple case study model was implemented choosing students from low, middle and high achievement from the pre-test to gain a more in-depth understanding of the
transition of mathematical understanding throughout the SSJY program as previously done in research (Kong, Wong, & Lam, 2003).

Creating the mathematical understanding and self-efficacy was a multi-step process that involved researching articles that had surveys that explored similar goals to this study (See Appendix ?). First, a search was performed through the National Assessment of Educational Progress (NAEP) database for examples of multiple choice and open-response questions to explore students understanding of the interpretation of graphical data. Second, search through the ERIC database for examples of surveys pertaining to mathematical understanding and self-efficacy. Next, I gathered several sample surveys that overlapped with the purpose. Then, I examined the surveys and highlighted items that were possible candidates for the survey. Given the purpose of the study, I divided the pre-survey into the following four sections about mathematics: understanding of graphical data (multiple-choice), mathematical self-efficacy of graphical data (Likert), understanding of graphical data (open response) and self-efficacy of using professional technologies such as the CommunityViz software (Likert). I made several revisions with the help of the two participating mathematics education professors and one science education professor.

The survey items comprised of four sections that included items exploring student mathematical understanding of graphing, self-efficacy of interpreting graphs, mathematical self-efficacy and technological self-efficacy (See Appendix A). The six multiple choice, mathematical understanding items were chosen from National Assessment of Education Progress (NAEP) tests from 1980-2011. The chosen questions involved items where the national average score was below 50% success. Of the six questions, due to a technical difficulty, only the first five questions were included in analysis as none of the answers were saved through the online
survey. These five items were graded as either correct or incorrect. The five items that explored self-efficacy of graphical interpretation were on a ten point Likert scale from not very comfortable to completely comfortable. The nine mathematical self-efficacy questions were on a four-point Likert scale from Strongly Disagree to Strongly Agree. The last section examining technological self-efficacy was on a ten point Likert scale from not very comfortable to completely comfortable.

These surveys were piloted in the summer of 2011 and revised by the research and reviewed by the same three professors. The first section includes questions that explore mathematical understanding of graphs. These questions were and are taken from the NAEP website (U.S. Department of Education, 2010) and were tagged as questions that fewer than 50% of students solved correctly in NAEP testing. The second section exploring mathematical self-efficacy of interpreting graphs, these five items were on a four-point Likert scale ranging from “not at all confident” to “very confident.” Asking questions like ‘If I do well on a question like this, it was because I worked hard,’ allows for students to answer questions about their perceived ability or the affective domain of their self-efficacy (Bandura, 1986; Tait–McCutcheon, 2008). Similarly, when students responded to ‘If I do well on a question like this, it was because it was easy,’ then the goal was to explore the cognitive domain to indicate students’ beliefs that hard work and familiarity of the material would lead to a stronger understanding of mathematical concepts. The goal of this section of the survey was to explore students’ self-efficacy during the process of interpreting graphs. The next section more generally was created to view students’ self-efficacy of the field of mathematics, having students complete items such as ‘I am good at math’ to ascertain their level of comfort within the cognitive domain of mathematical self-efficacy (Bandura, 1986; Tait–McCutcheon, 2008). This differs from the fourth section that also
explores students’ self-efficacy about the use of professional technologies that was on a ten-point Likert scale from ‘not at all confident’ to ‘totally confident.’ The goal of these questions was to explore students’ technological self-efficacy during the urban planning process by asking questions such as ‘I could complete the job using CommunityViz if there was someone given me step-by-step instructions’ in an attempt to understand students’ beliefs about the use of technology while learning about interpreting graphs (Compeau & Higgins, 1995; Lapp & Cyrus, 2000).

As many of the survey measures involved likert-scale questions with only 4 possibilities, constructed scales for each of the themes were created in order to explore if the overall themes had both reliability in the measures as well as showing statistical significance. These themes are explored further in Chapter 4.

Next, reliability tests were run to examine the constructed scales as indicated by Cronbach’s alpha, which examines the internal consistency of the scales within an instrument. These values were tested on constructed scales for groups of items attached to specific themes noted. The following were the three factors and their reliability: self-efficacy of interpreting graphs was constructed from six items which gave $\alpha = .754$ at the pre-survey level and $\alpha = .708$ at the post survey level; 3 attitudes toward using graphs in the real world from three items which gave $\alpha = .678$ at the pre-survey level and $\alpha = .612$ at the post-survey level; and technological self-efficacy from eight items, which gave $\alpha = .723$ at the pre-survey level and $\alpha = .699$ at the post survey level. The constructed scales for Self-efficacy for graphs and technology factors had generally high reliability levels and although the real world application constructed scales were slightly lower, this is attributed to using only three items for that particular scale.
One possible sample bias considered throughout the research project was the handling of missing data. An integral part of this research project is the pre/post survey. As some students started the program late or possible attrition over the two weeks, there is a possibility that there could be missing pre and post versions of this test. There are a number of alternative ways of dealing with missing data, and for this particular research project will be list-wise deletion. Thus, if subjects in the group did not show up to be tested, that group was not count in the data from those individuals (Cohen, Manion, & Morrison, 2000).

The first measurement was a self-administered pre-post survey. The rationale for this survey was twofold: (a) to create a baseline of student understanding of graphical representations and the opportunity to choose the ten students for the case study, and (b) to be able to show the change in understanding throughout the two-week institute. The survey created by the researcher was considered to be a non-standard, criterion referenced measure that comprised of 18 items, which were created to elicit student responses of how the level of understanding of graphical representations (dependent variable) were changed through the intervention (independent variable). The survey items comprised of six multiple choice questions, six long-answer questions and six problems that are student report about their own understanding of representing graphs that are on a Likert scale (See Appendix A). Of the six questions, due to a technical difficulty, only the first five questions were included in analysis as none of the answers were saved through the online survey. These five items were graded as either correct or incorrect. The open response and Likert scale questions were coded depending upon themes that emerged from the data during the initial analysis of the data that inform the overall understanding of students’ interpretations of the graphs. For further evidence and to learn more about the students understanding and self-efficacy, students were videotaped during the
SSJY program over the school year as well as during the summer institute. Finally interviews with ten students involved in the case study were taken at three different time points to triangulate the mathematical understanding and self-efficacy data.

**Interview and observation protocols.** The semi-structured interview protocols, which were part of the urban planning research project, were constructed by the researcher and reviewed by the PIs for the larger study (See Appendix B). The questions from the interviews and observations are informed by the work on understanding of graphical interpretations in real-world contexts (Penelope H. Dunham & Thomas P. Dick, 1994; Lapp & Cyrus, 2000; McDermott, et al., 1987).

Based on a pilot study, suggested changes were made to both the content and organization of the protocol. During the first year of the study, case participants were interviewed twice (see Table 3.3). The following themes are the foci of the interviews: educational background, self-efficacy and student mathematical understanding. The observation protocol is constructed in a similar manner as the interview protocol. According to Strauss & Corbin (1998) observations help to triangulate emerging findings and provide knowledge about the context of the study.

Observations were useful in examining participants’ understanding of the use of the technology and mathematical understanding of the graphical interpretations and urban planning. The group observations provided a firsthand examination of how participants’ mathematical understanding evolved overtime. They also allowed for a better understanding of the participants’ context in the SSJY program.
Artifacts

Several artifacts were collected through the urban planning program. In the first year of the program, students’ final PowerPoint Presentations were collected. During the second year, PowerPoint Presentations as well as final projects (See Appendix C) were collected and analyzed to measure for student mathematical understanding throughout the program.

Presentations and worksheets. Both the worksheets given to students and the final presentation templates had a focus on the understanding of the student-created graphs in Microsoft Excel and the computer generated bar graphs created by the CommunityViz software (Appendix C). Students were expected to use the graphs to explain the trade-offs that must be made between the ecological and economic impact that each of their created redesigns of the vacant lots. As well, students used the graphs to compare different re-designs that they have created to give evidence for choosing which site would be best to use for a re-design.

Data Analysis

Quantitative data analyses was carried out with SPSS, a software package used for organizing data, conducting statistical analyses, and generating tables and graphs that summarize data. This approach involved several steps. First, descriptive statistics were applied to analyze overall item response percentages and to note any possible trends in survey responses. Second, correlations examined the relationships between student mathematical understand between pre and post survey data as well as mathematical self-efficacy. Paired t-tests were then completed to compare the differences in mathematical self-efficacy and understanding over the course of the study.

Once the interview and observational transcripts were completed, the text was coded so that each activity system was assigned a descriptor intended to capture the essential meaning.
This initial coding stage, also referred to as “open coding” (Strauss & Corbin, 1990), was the first effort at collapsing the data into a more manageable size. The next phase was an attempt to seek patterns within the data. This effort to introduce structure into the data set was influenced by the theoretical frameworks of the study. Final categories was established to capture the data and build a plausible set of relationships between the categories and concluding with an overall model describing the data set (Strauss & Corbin, 1990). Table 3.3 presents information that describes the units of analysis.

Table 3.3

*Data Collection and Analysis*

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Participants</th>
<th>Frequency per Participant</th>
<th>Totals</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Self-efficacy and Mathematical Understanding Survey</td>
<td>62 students</td>
<td>At 2 different time periods</td>
<td>80 total surveys</td>
<td>Using this as quantitative data for descriptive statistics and looking for statistically significant changes through a means test to view differences in self-efficacy and understanding throughout the program</td>
</tr>
<tr>
<td>Semi-structured Interview</td>
<td>10 students</td>
<td>Pre and Post Interviews</td>
<td>20 Interviews</td>
<td>Content analysis related to: - Mathematical Understanding (Carpenter) - Self-Efficacy (Bandura) Iterative coding of new concepts</td>
</tr>
</tbody>
</table>
### Limitations of the Design

The over-arching design of this examination of students’ self-efficacy and mathematical understanding mediated by technology is that it is described by a bounded case study of ten students. To date, I am not aware of any study that involves the investigation of using urban planning technologies to mediate the learning of mathematical tasks.

Although the case for using this bounded case design has been made previously, there are still areas of concern in this research design. In qualitative research there is a trade-off between the comparative opportunities provided by multiple-case analysis and the potential for rich description of context afforded by single-case studies (Miles & Huberman, 1994). The sample given could be improved by adjusting the number to more than ten students.

Great care was taken to represent interviews and interpretations of video through the perspective of the students. However, ultimately these interpretations are explored and written by
the author. This is to be taken into consideration as this information is disseminated through the research field.

Stake (2000) called this approach to case study, instrumental case study, as its goal is to "provide insight into an issue or redraw a generalization" (p. 436). Even so, the nature of case study is inherently concerned with “particularization,” not generalization, as the uniqueness of the specific case is as important as the insight provided about a larger number of cases (Stake, 1995, p.8). Therefore, researchers who undertake case study must acknowledge that by operating with the simultaneous intermingling interests of the particular and the general, significant limitations in the ability of the case to represent the larger issue at hand remain (Stake, 2000).

The quantitative data also presented limitations. Overall, there was a low sample size that completed both the pre and post survey. It would have been beneficial to have more students that took both the pre and post survey. As this was a descriptive study, the only students that completed the survey were students that were involved in the SSJY program. Having a control group taking the survey as well would have led to the ability to see how students that were involved in the SSJY urban planning project differed in mathematical self-efficacy and understanding from those that did not.
CHAPTER 4
SURVEY RESULTS: SELF EFFICACY AND MATHEMATICAL UNDERSTANDING OF
GRAPHICAL INTERPRETATIONS

The goal of this chapter was to examine four different constructs: students perceptions of using graphs in day-to-day life and the SSJY program, student mathematical understanding of interpreting graphs on the National Assessment of Educational Progress (NAEP, 2010) graphing questions, students self-efficacy in interpreting and using graphs and students self-efficacy in mathematics. Surveys were administered to SSJY students in the urban planning project (n = 62) during the first and final day of each urban planning project throughout the year. The pre-survey sought to capture participants’ entering mathematical understanding, self-efficacy about mathematics and interpreting graphs as well as their perceptions of graphs in mathematics. The purpose of the post-survey was to examine possible changes in mathematical understanding and self-efficacy throughout the urban planning project. Analyses consisted of correlations, paired t-tests, and regression models to examine students’ mathematical understanding and self-efficacy. What follows is an interpretive summary of the findings.

As mentioned in Chapter 3, part of the data collected for this study included a survey for students enrolled in the SSJY program. In this chapter the results from the analysis of this survey are presented. Explicitly, this chapter is an examination of the following sub-set research questions in Chapter One:

a) How does the implementation of GIS and EXCEL technology in the SSJY program influence self-efficacy as students interpret graphical representations of data?

b) How is the mathematical understanding of graphical representations influenced by the introduction of GIS and EXCEL technology in the SSJY program?
Carpenter (1992) argues that mathematical understanding is a structure or network of mathematical ideas or representations comes out clearly from the literature. Bandura (Bandura, 1977, 1986) argues that student self-efficacy ought to be a focus of educational research because self-efficacy can influence both perceptions and behaviors. Specifically, mathematics education research also maintains that one’s prior knowledge and self-efficacy strongly affect how one makes sense of new ideas (Schoenfeld, 1992; Tait–McCUTCheon, 2008).

The first section of this chapter explains the survey data analysis (n=57), including a description of the variables, descriptive statistics, missing data, test scores and paired t-tests. Taken together, the findings presented in this chapter demonstrate that there is a statistically significant increase in students’ mathematical understanding and self-efficacy of interpreting graphs. An interpretive summary of the survey results is provided to position findings within the literature on student self-efficacy and mathematical understanding.

**Survey Results**

**Initial Analysis**

Initially, descriptive statistics of pre/post-survey items were examined to determine any unusual patterns or trends. Although no unusual values were detected, there was an issue of missing data, which is addressed in the next section. Descriptive statistics of items were also examined to guide selection of the variables used in the analyses.

In terms of the theoretical framework of Activity Theory (AT) this survey data will be used for two reasons: (1) to use students’ scores on National assessments to strengthen the case for the increased learning and understanding of interpreting graphs as a result of the SSJY Urban Planning Project and (2) to be used as a form of triangulation for evidence in the nested activity systems for increased self-efficacy of interpreting graphs throughout the Urban Planning Project.
Missing Data

After an initial analysis of the data it was noted that five of the items had missing data. There were two items from the pre-test and three items from the post-test that were missing. The pre survey missing data was replaced with an unconditional mean substitution by replacing each missing value with the mean of the observed data for the variable in question. Although this can reduce the variance of the scores, for the two instances where there were missing data, since responses were not present; therefore, an unconditional mean substitution would not have a major influence on the spread of the data. It was important to replace missing data, because the sample size was fairly small; three cases were about 3.5% of the total sample size. This helped to avoid statistical analysis issues with missing data. For the three items with missing data on the post-survey (about 5.2% of the total sample size), I replaced missing data with a conditional mean substitution in order to enter a value closest to what was expected. To compute an expected value, I looked at participants’ pre-survey responses and replaced their post-survey response with the mean score of those who had the same responses on the pre-survey. From this point forward, the survey items elected for examination for this analysis will be described as variables for each of the four sections in the pre/post survey.

Variables

Within this chapter, there are five areas that emerged from the data collected in the pre/post survey. Instead of listing each individual question in the survey results, the variables below have been created for ease within the discussion. A description of the constructs denoted in the surveys and their assigned variables are outlined according to these five themes.

Mathematical understanding of interpreting graphs. The dependent variable mathematical understanding served as a measure of content knowledge for interpreting graphs.
The survey gave a score out of 100 percent on students’ proficiency of a mathematics test. Although, there are many dimensions to students' understanding of mathematical concepts, and multiple measures are better indications of this knowledge, for the purposes of this study, a general sense of student mathematical understanding of interpreting graphs was valuable.

**Self-efficacy of interpreting graphs.** The independent variable *graphing self-efficacy* was a measure of one's own ability to complete tasks and reach goals during the urban planning project. Several items from the survey such as "graphs do not make sense to me" were used to explore students’ self-efficacy of interpreting graphs throughout the SSJY program.

**Student self-efficacy in using professional technologies.** The independent variable *technological self-efficacy* involves the belief in one’s ability to successfully perform a technologically sophisticated new task. For this intervention, specifically exploring the students’ use of professional urban planning software (CommunityViz).

**Perceptions of interpreting graphs.** The independent variable of *perceptions graphs* was used to determine students’ perceptions of graphs during the intervention. Questions like “Mathematics is easier to do if I can look at a graph" were intended to explore students’ perceptions over the time of the intervention.

**Mathematical self-efficacy.** The independent variable *mathematical self-efficacy* indicated participants’ confidence in mathematics. The item stated, “I am good at mathematics” or "I am not very good at mathematics” was an indication of mathematical self-efficacy.

**Students Learning Mathematics in SSJY**

The urban planning project is part of a larger NSF funded grant exploring students STEM interest and career development. This research project was a subset specifically exploring students’ ability to interpret graphs in mathematical tasks that are contextually meaningful. One
of the questions on the survey “I use mathematics when I am at SSJY” was used to look at students perceptions of mathematics that are involved in the SSJY program. The results of the pre/post survey showed that there was a statistically significant difference in students perceptions of the use of mathematics in the program ($\mu: 2.8529$ to $3.2353$, $t = 2.4191$, $p = 0.0106$).

Two other measures also were added to the survey to look at students perceptions of the use of graphs in mathematics throughout the Urban Planning Project. Paired $t$-tests with a 95% confidence level were used to explore students’ perceptions of the use of graphs in mathematics at the beginning and the end of the intervention as seen in Table 4.1.

Table 4.1

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Pretest M</th>
<th>Pretest SD</th>
<th>Posttest M</th>
<th>Posttest SD</th>
<th>df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics is easier if I look</td>
<td>4.88</td>
<td>0.63</td>
<td>5.82</td>
<td>0.76</td>
<td>56</td>
<td>1.96*</td>
</tr>
<tr>
<td>at a graph</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphs can help with presenting</td>
<td>3.00</td>
<td>0.43</td>
<td>3.04</td>
<td>0.68</td>
<td>56</td>
<td>2.26*</td>
</tr>
<tr>
<td>difficult math</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$p<0.05$  

Both of the items of student perception showed a statistically significant increase of students’ perceptions of graphs from the beginning and the end of the intervention. These results indicate that the involvement in these real-world mathematical tasks show an increased perception of the use of graphs in terms of the cognitive domain of self-efficacy (Bandura, 1986; Tait–McCutcheon, 2008) as a viable tool for solving and interpreting mathematical concepts.

**Mathematical Understanding of Interpreting Graphs.**

According to Hiebert and Carpenter (1992):

> The mathematics is understood if its mental representation is part of a network of representations. The degree of understanding is determined by the number and strength of its connections. A mathematical idea, procedure, or fact is understood thoroughly if it is linked to existing networks with stronger or more numerous connections. (p. 67)
To explore mathematical understanding based on Hiebert and Carpenter’s prospective in regards to the pre/post survey items, this definition is examined from two concepts: (1) To understand mathematics is to make connections between mental representations of a mathematical concept, and (2) Understanding is the resulting network of representations associated with that mathematical concept (Hiebert, et al., 1997). Specifically, this survey explored mathematical understanding from the first concept, considering how the connections from the Urban Planning project linked to their mental representations of mathematical concepts for general questions from the NAEP (2010) that involve students interpreting graphs. Questions were chosen by level of difficulty. Five questions were chosen that had success rates where fewer than fifty percent of the students nationally solved them correctly.

The five questions were initially analyzed individually using a paired $t$-test with a two-tailed 95% confidence interval to explore if there was a statistically significant increase in students’ scores from each of the selected items of understanding, as noted in Figure 4.1.

![Figure 4.1. Students pre and post grades for each of the five understanding survey items](image)

The grades for the questions were then scored as a grade out of 100%. Analyzing the data from pre-survey to post-survey there was a statistically significant increase in the students
mathematical understanding from pre-test to post-test \( (t = 9.3597, p < 0.001) \). Over the length of the Urban Planning Project there was a significant increase in student scores on National assessment questions that involved interpreting graphs.

**Student Self-efficacy of Interpreting Graphs**

Initially, six of the items were constructed together to do an initial paired t-test to explore the statistical significance of student self-efficacy of interpreted graphs as seen in table 4.2

Table 4.2

<table>
<thead>
<tr>
<th>Items</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>If I did well on a question like this, it was because it was easy.</td>
<td></td>
</tr>
<tr>
<td>If I do well on a question like this, it was because I worked hard.</td>
<td></td>
</tr>
<tr>
<td>I feel confident in my ability to express what is written on a graph.</td>
<td></td>
</tr>
<tr>
<td>I am not so good at mathematics.</td>
<td></td>
</tr>
<tr>
<td>It is important to use graphical representations to explain what I learn.</td>
<td></td>
</tr>
</tbody>
</table>

It was noted that there was a statistically significant increase from pre-survey to post-survey from this constructed scale \( (t = 6.7619, p = <0.0005) \). With these positive results, what follows is a list of smaller groups and individual questions where paired t-tests were conducted to determine significant differences in the mathematics attitude and graphing self-efficacy over the course of the Urban Planning Project (see Table 4.3). These items were implemented to explore the students’ internal belief system according to their ability in interpreting graphs (Bandura, 1986; Tait–McCutcheon, 2008). The paired t-test was run with a two-tailed 95% confidence interval. Results indicated that the students in the Urban Planning Project had statistically significant positive changes in their attitudes towards interpreting graphs. They also became significantly more self-efficacious in their overall ability to interpret graphs.
Table 4.3

**Statistical Differences of Self-Efficacy of interpreting graphs on Pre/Post-Survey Results**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Pretest M</th>
<th>SD</th>
<th>Posttest M</th>
<th>SD</th>
<th>df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>If I did well on a question like this, it was because it was easy.</td>
<td>6.32</td>
<td>2.73</td>
<td>7.32</td>
<td>2.62</td>
<td>56</td>
<td>2.94*</td>
</tr>
<tr>
<td>If I do well it was because I worked hard.</td>
<td>5.94</td>
<td>2.71</td>
<td>7.06</td>
<td>2.27</td>
<td>56</td>
<td>2.06*</td>
</tr>
<tr>
<td>I like solving questions like this; it is like solving a puzzle.</td>
<td>5.00</td>
<td>2.06</td>
<td>7.17</td>
<td>2.30</td>
<td>56</td>
<td>4.62*</td>
</tr>
<tr>
<td>I feel confident in my ability to express graphs.</td>
<td>2.73</td>
<td>0.57</td>
<td>3.17</td>
<td>0.64</td>
<td>56</td>
<td>3.46*</td>
</tr>
</tbody>
</table>

*p<0.05.

*Figure 4.2.* Results of self-efficacy graphing item.

**Student Self-efficacy in Using Professional Technologies**

To test if there was a statistical significance overall for technological self-efficacy, a t-test analysis was completed on a constructed scale of all of the measures to explore statistical significance first from the scales in Figure 4.3.

*Figure 4.3*

**Construct scale for technological self-efficacy**

**Technological Self-efficacy**

Questions

I could complete the task at hand using
Excel/CommunityViz if...

…if there was someone given me step-by-step instructions.

…if there was no one around to tell me what to do as I go.

…if I had never used software like it before.

…if I had seen someone for help if I got stuck.

…if someone else had helped me get started.

…if I had a lot of time to complete the job for which the software was provided.

…if I had just the computer help for assistance.

…if I had used similar software before this one to do the same job.

After a t-test analysis, it was noted that there was a statistically significant increase from pre-survey to post-survey in students’ overall beliefs about their technological self-efficacy ($t = 5.1860$, $p = <0.0005$). After this test, paired-sampled $t$-test were conducted to compare the pre and post survey results for smaller subsets and individual technological self-efficacy questions for the use of CommunityViz and Microsoft Excel during the Urban Planning Project. Each question started with ‘I could complete the task at hand using Excel/CommunityViz if...’ Analysis of these items indicates that there are significant differences. Results are displayed in Table 4.4.
Table 4.4

Statistical Differences  Technological Self-Efficacy on Pre/Post-Survey Results

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>...if there was someone given me step-by-step instructions.</td>
<td>4.88</td>
<td>5.82</td>
<td>56</td>
<td>2.98*</td>
</tr>
<tr>
<td>...if there was no one around to tell me what to do as I go.</td>
<td>3.91</td>
<td>5.94</td>
<td>56</td>
<td>1.96*</td>
</tr>
<tr>
<td>...if I had never used software like it before.</td>
<td>2.73</td>
<td>3.18</td>
<td>56</td>
<td>3.90*</td>
</tr>
<tr>
<td>...if I had a lot of time to complete the job.</td>
<td>5.18</td>
<td>6.09</td>
<td>56</td>
<td>3.26*</td>
</tr>
<tr>
<td>...if I had just the computer help for assistance.</td>
<td>6.92</td>
<td>7.90</td>
<td>56</td>
<td>1.97*</td>
</tr>
<tr>
<td>...if I had used similar software to do the same job.</td>
<td>4.88</td>
<td>5.82</td>
<td>56</td>
<td>2.51*</td>
</tr>
</tbody>
</table>

* p<0.05.

However, for three questions that involved getting help from others, analysis revealed that there were no statistically significant differences as illustrated in Table 4.5

Table 4.5

Statistical Differences Self-Efficacy of interpreting graphs on Pre- and Post-Survey Results

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>...if I had seen someone for help if I got stuck.</td>
<td>6.17</td>
<td>6.71</td>
<td>56</td>
<td>1.19</td>
</tr>
<tr>
<td>...if someone else had helped me get started.</td>
<td>6.85</td>
<td>7.35</td>
<td>56</td>
<td>1.14</td>
</tr>
</tbody>
</table>

These results specify that the survey items that considered teacher involvement in promoting students’ self-efficacy of technology did not change significantly over the length of the intervention.
Figure 4.4. Pre/Post Survey Results for ‘if someone else had helped me get started.

Because these items were high at pretest and showed limited or no increase at posttest, there is the likelihood that there was a ceiling effect (Figure 4.4). Furthermore, these items were the only ones that were not statistically significant for this section of the survey. This indicates a potential for future research in the effectiveness of teacher led instruction of the use of educational technologies on the technological self-efficacy of students.

Student Self-Efficacy in Mathematics

As noted earlier in this chapter, there was a statistically significant increase in the self-efficacy of interpreting graphs for students in the SSJY program as a result of the urban planning intervention. To explore a more general view of students’ mathematical self-efficacy, two survey items were analyzed. These two questions are noted in Table 4.6.

Table 4.6

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Pretest</th>
<th></th>
<th>Posttest</th>
<th></th>
<th>df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am good at mathematics.</td>
<td>3.18</td>
<td>0.63</td>
<td>6.71</td>
<td>0.95</td>
<td>56</td>
<td>1.30</td>
</tr>
<tr>
<td>Mathematics is not necessary in everyday</td>
<td>2.00</td>
<td>2.34</td>
<td>7.35</td>
<td>1.01</td>
<td>56</td>
<td>-0.37</td>
</tr>
</tbody>
</table>
Also, a paired t-test to analysis reveals that the means of these two survey items did not change significantly from pretest to posttest during the intervention ($p = 0.1006$ and $p = 0.5441$ respectively). There may be a disconnect between student self-efficacy regarding what is learned (the intervention) and students’ overall self-efficacy related to mathematics.

Conversely, using paired t-test to analyze the same two survey items using gender as a mediating variable demonstrates different findings. Mean scores (from pre to post-test) elicited from male participants were not statistically significant for either item ($t = 1.1448, p = 0.1351$ and $t = 0.6202, p = 0.5000$ respectively). However, for the survey item ‘Mathematics is not necessary in everyday living,’ there was a statistically significant difference in mean scores exhibited by female participants ($t =-2.8291, p = 0.0058$). This demonstrates a difference in how females in the SSJY program view mathematics in day-to-day life after the urban planning intervention as compared to male participants in the same program.

**Interpretive Summary**

This chapter is an analysis of SSJY student’s mathematical understanding and self-efficacy of interpreting graphs during the Urban Planning Project. Surveys were administered to SSJY students ($n = 57$) during the beginning and end of each students Urban Planning Project. The pre-survey sought to capture participants’ entering mathematical understanding and self-efficacy about mathematics and interpreting graphs. The purpose of the post-survey was to examine possible changes in students’ mathematical self-efficacy and understanding. Analyses consisted of students’ results for their mathematical understanding test and paired $t$-tests to examine how the Urban Planning Project related to SSJY students mathematical understanding and self-efficacy. What follows is an interpretive summary of the findings.
Findings indicated that there was a statistically significant increase in the students’ mathematical understanding of interpreting graphs. On a measure with five questions taken from the NAEP test website (NAEP, 2010) that involved the interpretation of graphs. It is noted from mean scores that students performed statistically significantly higher from pre-test to post-test (t = 9.3597, p <0.001). This indicates that as a result of students’ involvement in the Urban Planning project, an overall understanding of using graphs in real-world situations has given students an increased understanding of solving questions that involve graphical representations. These findings support a qualitative study conducted by Lapp & Cyrus (Lapp & Cyrus, 2000), who examined students use of professional technologies to solve real-world mathematical problems. They found that using examples of real-world problems with the assistance of technology led to students increased understanding of mathematics on questions in State-wide assessment problems that involved interpreting graphical data.

A positive increase in students’ self-efficacy of interpreting graphs was found in several self-efficacy measures in the pre/post survey noted in Table 4.2 which suggested that the experiences from the Urban Planning project had a positive relationship on the students’ confidence to solve real-world problems with the interpretation of graphs. This is logical; at the high school level, mathematical content becomes more challenging, and those with a more positive experience were more likely to have succeeded.

Although there was a positive increase in student self-efficacy of interpreting graphs during the intervention, the two survey items that involved student self-efficacy in general mathematics were not statistically significantly different from pre to post testing. Items such as 'I am good at mathematics.' or 'Mathematics is not necessary in everyday living.' did not show statistically significant differences (t = 1.3042, p = 0.1006 and t = -0.3728, p = 0.6441
respectively). However, with further analysis with respect to gender indicate that there was a statistically significant difference in female responses to the item 'Mathematics is not necessary in everyday living' ($t = -2.8291, p = 0.0058$). These results indicate the need for future research into gender perceptions of mathematical self-efficacy during similar interventions to this one.

Pre- and post-surveys about technological self-efficacy with the use of professional urban planning technologies were administered during the beginning and end of students involvement with the Urban Planning Project. Results indicated that the students' individual self-efficacy showed signs of a statistically significant increase as noted in Table 4.3, while the survey items that involved the students getting help from an instructor to help with their technological self-efficacy did not show a statistically significant change. Although this could be an indication of a ceiling effect with the higher values at the pre-test level, this could also indicate the need for future research in exploring teachers' involvement in student technological self-efficacy in mathematics both in and out of school environments.

Findings presented in this chapter suggested that students' mathematical understanding and self-efficacy of interpreting graphs increased as a result of the Urban Planning Project. Although findings from the surveys provided a better understanding about the students in the SSJY program, the next chapter extends this study to examine what happened for ten specific students over the length of the Urban Planning Project through the analysis of classroom interactions and documents these ten students created and presented over the SSJY program. Their experiences of learning about urban planning and how mathematics relates to this project will be investigated through these case studies.
CHAPTER 5  
CASE STUDIES: SELF-EFFICACY AND UNDERSTANDING GRAPHICAL DATA  

As discussed in Chapter One, a major goal of this research is to describe students’ technology experiences in an effort to understand the impact of decisions in urban planning through the analysis of the mathematics (graphing) learned during the urban planning project. Therefore, the findings that emerged from analysis of the data are presented through multiple case studies drawn from survey, interviews and observations from ten students’ learning experiences about urban planning and graphical interpretations during the SSJY program. The purpose of the case studies was to capture the learning experiences of the participants from their own perspectives. The emphasis is on examining their experiences to make sense of how they developed their mathematical self-efficacy and their understanding of graphical interpretation of data (Bandura, 1977, 1997; Hiebert, et al., 1997; Lapp & Cyrus, 2000). A careful and in-depth analysis of the data collected over a two-year period provided a holistic picture of the participants’ experiences, addressing the research questions outlined in Chapter One.

The case studies were specifically structured to address the elements of the Activity Theory conceptual framework outlined in Chapter One. For example, the background information from interviews and observation data permitted explanations of the characteristics the participants brought into the program, followed by findings from the students’ experiences in the SSJY program. Next, the analysis was extended into their work during the urban planning program, incorporating observations and student work samples. Finally, there is a summation of the relationships among participants’ experiences, and how that influenced students’ self-efficacy and mathematical understanding.
This chapter presents the cases of ten students who leveraged the CommunityViz technology to make urban planning decisions in SSJY, using data collected over a two-year period from interviews, observations and student work. Pseudonyms are used for all participants to protect their identity. Organized by research question and theme, I present the findings in six sections. Section one presents a portrait of each participant, followed by the individual results from the pre/post survey offered in Chapter 4. The next section includes findings emerging from analysis of interview data in which students describe their in and out of school experiences with mathematics as well as their understanding of the mathematical concepts learned in the SSJY. The next two sections consist of findings that detail separate observations of the students that support both the self-efficacy and the experiences in understanding the mathematical concepts learned during the urban planning project. The focus of the observations was primarily to explore the students’ use of graphs in Excel and CommunityViz to make decisions about the urban plans that would benefit their neighborhoods. Each episode begins with an activity quote, the activities where technology is used, and the outcome (how students respond to activities).

**Portraits of Ten SSJY Students**

To understand the unique backgrounds of students participating in the SSJY program, this chapter begins with a review of the individual students. Thus, brief portraits of ten students participating in the Urban Planning Project are offered. These portraits are meant to describe trends in the profiles of the ten individuals studied. Following these portraits are explanations of the overarching themes across all ten of the students, describing their experiences during the Urban Planning Project.
Jaleesa, “I am Usually Wrong”

Jaleesa joined the SSJY program the summer after graduating from the 8th grade. She was accepted into SSJY along with other students and was placed in the Urban Planning project. She entered ninth grade as an intermediate level student taking Algebra 1. Jaleesa was part of the urban planning program for one year before she was moved to another strand of the program. Over the year there were many opportunities to observe and interview Jaleesa about her experiences in the UPP.

When asked about her experiences in mathematics before she started the program, Jaleesa mentioned that she liked a traditional mathematics experience where the teacher “[converses] with you and tell you what you have to do and gives an example on how it is supposed to be done and then we do examples.” She had indicated several times during the interviews that she was concerned about mathematics because she was “usually wrong” when learning mathematics.

Before the UPP intervention, she explained that her mathematical experiences outside of school consisted of using money when she went to the store, making change, making sure that she had enough money to get what she needed. However, after the UPP intervention, she felt that her mathematics experiences expanded to the work done at SSJY where she was learning to use graphs to “easily understand math for the project.” She stated that using technology like CommunityViz made it more interesting and helped with her understanding of “the math.” Jaleesa enjoyed the program throughout the year, but looked forward to having the time in the summer to “really get into the urban planning” as she believed that having the intensive summer two-week institute allowed her to have more time to explore urban planning decisions.
Jo, “Graphs are like doing the puzzle of math”

Starting the program in the fall, Jo had a strong influence on the UPP. She was a very outgoing individual and was usually the first person to answer questions asked by the instructors. Jo joined as a ninth grade student and she was enrolled in Algebra II at her high school. The usual path for students in this district is to start with Algebra I in 9th grade, followed by Geometry. Taking these advanced mathematics classes at an early age was notable as it showed her advanced knowledge of mathematics going into the project. In total, Jo was part of the urban planning project until the following summer when she switched to a new strand of the program the following fall.

Jo considers herself a visual learner and this did not change over the two years she was involved with the UPP. However, over time she started to realize that her strength as a visual learner helped with her work while participating in the UPP. The use of graphs to represent the data for urban planning helped with her overall understanding of the data; also, the graphs helped her develop understanding of mathematics in which she described, “doing the puzzle of math.”

Jo description of using mathematics outside of the classroom included using mathematics for baking, when she needed to calculate how much sugar to make half of a recipe. Initially, she did not believe that the work completed in the SSJY program involved doing mathematics. However, after more than a year in the UPP, her beliefs changed because she thought that she did more mathematics in the SSJY than she did in school. Furthermore, the graphs that were created from CommunityViz were key to answering questions asked about urban planning. Jo explained, “Graphs: helped us describe the difference between groups and things like that.”
Andy, “The more strategies I have, the more ways I can solve a problem.”

Andy was involved in the UPP for one and a half years. He entered the program in tenth grade, taking Geometry in school, which is common for students in this school district. When Andy first entered the program he was very shy; however, he took an immediate interest in the UPP and urban planning in general. Resultantly, he became one of the top students in the program and is currently a student leader for the project.

Andy considered mathematics to be his favorite subject and believed that learning many different ways to solve mathematics is the best way to learn. As he mentioned, “the more strategies I have, the more ways I can solve a problem.” He likes it when a teacher breaks down mathematics and when the teacher does examples on the board. Yet, he stated that there were times when he struggled with problems on his own. After the UPP intervention, he realized that he liked doing mathematics that was “real-world,” explaining, “Doing problems on your own does get confusing. It feels good to solve a problem in my neighborhood on my own.”

During a discussion about applying and learning mathematics outside of school, he stated that he used mathematics a lot when playing music. He declared, “So, instead of A through G, I have one through six and the black keys [that are] on top I have them as halves, so I can remember them easily.” Initially, he did not believe that he engaged in mathematics during his participation in the SSJY program. However, after a year in the UPP, he noted examples of applying mathematics concepts and skills. For example, he recognized that he was applying mathematics when he figured out the total surface area within a created site or found certain distances between two points in a certain area. He noted that mathematics might be helpful to assist with his analysis, declaring, “For example, the street we had trouble parking on [was] narrow. I tried to measure the little opening that we were trying to get into, so we can see how
wide we can have a certain opening; so that we can have the parking lot there and stuff like that, the site that I’m working on.” He believed that using the graphs allowed him to make a decision between which redesign would be better. He said, “Doing research on different sites to make a good estimate [of] what the actual price would be. I don’t know. Planting trees in Boston or residential buildings and stuff like that, it helps.”

Jerry, “All of the graphs”

Although only involved in the SSJY program for the school year from September to May, Jerry was a leader in the UPP and was helpful to many of the students. He was a twelfth grade student taking AP Calculus and was accepted to a top ranked college once he graduated.

When asked about how he liked to learn mathematics, Jerry mentioned that he liked a lot of traditional mathematics where the teacher gives plenty of examples and then he does similar practice. After the UPP intervention, he believed that a lot of practice was still the best way to learn mathematics; however he added that learning about doing real-world math in groups was very helpful and that he learned a lot when he did mathematics in groups.

In a discussion about mathematics that was completed outside of his Calculus class, he cited that he appreciated thinking about mathematics and money. He thought a lot about making lots of money in the future. For example, he considered how much money he would make per hour if he knew his annual salary. He liked statistics and really enjoyed doing the interpretations of graphs in the UPP because of “all of the graphs.” For instance, Jerry liked working with data concerning temperatures and sound pollution to make decisions about how to redesign a vacant lot. He said that there was a benefit to having extended time in the summer to “have full days” to sit and talk to instructors and other students about the work and discuss different urban plans.
Mercedes “Google Earth in the SSJY”

Mercedes joined SSJY when she was a high school junior and she was enrolled in a Pre-Calculus course at her school. During her senior year of high school she switched to another strand of the SSJY program. She expressed great excitement when she started to participate in the UPP real world activities; she acknowledged that the best way to learn mathematics was engaging in physical, hands-on mathematical activities. Her idea about what makes a good mathematics teacher is one who uses interesting real-world examples in class to capture the attention of students.

Mercedes was very straightforward in providing examples of how she applied mathematics outside of school. She cited that she used mathematics when she shops, especially when she had to make change. Another example that she provided of when she used mathematics was her involvement in church fundraising activities. She also enjoyed finding distances and GPS coordinates using “Google Earth in the SSJY.” After a year of the SSJY, she used mathematics to calculate space available to build certain buildings on her re-design of the park.

Samantha, “All that urban planning stuff is all math”

Samantha entered the SSJY program as a tenth grade student and was in enrolled in Geometry at her high school. When she was involved in the UPP, she had many insightful thoughts on urban planning; however, her attendance was sporadic and she missed several of her group presentations.

Samantha believed that mathematics was her biggest struggle and she was not able to describe any meaningful experiences with mathematics to date. She also believed that doing hands-on and “real-world” mathematics made it more engaging and enjoyable. Although, at the
end of the program she still felt mathematics to be a struggle, her involvement with the program solidified her believe that mathematics in real-world contexts helped with learning. She added that if she had to do mathematics problems, she preferred to be in a quiet room by herself so that she could concentrate. She said if she struggled with a mathematical concept or skill, she would learn more from an Internet search for solutions instead of learning from a teacher.

Throughout the UPP intervention, Samantha enjoyed reading graphs in the news because she believed that this was “the best way to understand data.” She stated that being involved with the various activities, especially “all the graphing stuff” that was done in the program was very enjoyable. She believed that for urban planning projects using graphs was the best way to learn about distance and mileage. She explained, “Yeah, all that urban planning stuff is all math. That’s all real-life math. Right, so all that stuff absolutely counts and you can use it in real life.”

**Julio, “Doing graphs is mathematics”**

Julio came to the SSJY the summer before he started ninth grade and was enrolled in an Algebra 1 course in the fall. He was involved in a two-week intensive summer UPP project and continued with the project during the fall until the conclusion of the program.

According to Julio, he struggled during his mathematics lessons at his high school because of a lack of focus on mathematics. He stated during mathematics class, he had to tune out his teacher and then he would go home, study and solve problems repeatedly until he got them right. Throughout the UPP, he learned the importance of doing mathematics in groups and to look at different ways to solve problems.

Outside of his mathematics classes, Julio used mathematics when he was using money and working through his daily schedule. He stated that he always went with his mother to the
grocery store, so that he could figure out what to buy. In particular he explained that he is very familiar with the family budget and when they would shop for groceries he decided what type of each item to buy for the family, in order to stay under their daily budget. After weeks of his involvement in the urban planning project he revealed that “doing [activities involving] graphs is mathematics”, that there were other opportunities to learn mathematics outside of the class room and thus, analyzing graphs helped him figure out the cost of buildings and assisted him in determining which urban plan was the best option for the project.

Shanel, “Graphs have to do with numbers and stuff”

Shanel joined SSJY in the summer before her eleventh grade year of high school. She enrolled in an Algebra II course for the fall; she expressed some nervousness about the upcoming academic year. Shanel enjoyed learning mathematics that involved visual, hands-on lessons and activities. These types of lessons were not what she typically engaged in during her mathematics class at her high school. However, she could recall an activity in which she had to complete a three-dimensional model of her high school to scale.

Because of her understanding of mathematics and her understanding of the English language, she often helped her mother pay her bills. She believed that she did mathematics in SSJY when “we’re doing graphs, and [graphs] have to do with numbers and stuff.” She enjoyed doing mathematics with the help of technologies such as the CommunityViz, the Internet and PowerPoint.

Dash, “It’s something different for me”

Dash entered the UPP for the two-week intensive summer session after graduating from high school and he was only involved in SSJY for that time period. Dash enjoyed mathematics
because as he mentioned, “I have a lot of support to learn math, tutors, and etcetera.” He also stayed most days after school to get extra help with mathematics assignments. He liked learning new things that had to do with mathematics and he enjoyed using the technologies of the UPP because this was his first experience using technologies like CommunityViz and Excel. “I’ve never made graphs from those two programs before [but] I liked it. It’s something different for me,” Dash stated. In a discussion about doing mathematics outside of school, he mentioned the SSJY program, explaining that he liked creating graphs to explore temperatures around the parks they visited.

**Giovanni, “I like to break down the numbers when I learn math”**

Giovanni was another high school graduate that was involved in the UPP for the two-week intensive program. When learning mathematics, he preferred that his teacher break down mathematics examples into parts. He also stated that he enjoyed learning and using statistics.

Giovanni was able to highlight several ways he used mathematics outside of formal school instruction. Some examples included buying food, deciding on tips, and figuring out how much he would save on sale items in stores. In SSJY he said that there was a lot of mathematics that had to do with temperatures; thus he enjoyed engaging in activities that involved working temperatures.

**Self-Efficacy**

“It’s like I tell people, ‘I’ll be shootin’ threes’ even if I can’t, cause I’m confident”

One way to gain insight into learners’ feelings, thoughts, and actions with respect to mathematics is to examine their psychological domains of functioning: the affective, the cognitive, and the conative. It is important to examine each domain, as a student may feel
efficacious within the affective domain but less confident within the cognitive domain. What follows takes into account the ways in which these three domains interact and contribute to the ten students’ mathematical experiences both in and out of the SSJY program.

**Affective Domain**

Throughout the SSJY program, students were interviewed at the beginning and end of each project year. One question was asked specifically to examine students’ affective beliefs regarding their mathematics ability on a Likert scale from one to ten. In the pre-test the average score for students interviewed was 6.23, while in the post-test the average score was 7.81. The following is a description of the pre-test and post-test results, noting differences in the affective self-efficacy for some of the students in SSJY during the Urban Planning Program.

When students were asked how they would rate their ability in mathematics at both the pre-test and post-test time periods, many students discussed how mathematical ability was related to mathematical interest. It seemed that those expressing little interest in mathematics also thought they could not do mathematics. Analysis of data revealed students believed that you are good at what you like and you like what you are good at. Consequently, the students who were naturally good at mathematics believed they could change their mathematical ability; however, those who did not like mathematics both expected and accepted failure. The students’ comments reflect this perspective as they rate their ability in mathematics.

**Dash:** I’d say seven, around that range. It depends on the problems. The simple fact is word problems are kind of hard and boring sometimes.

**Samantha:** I would say a 3. My math skills are not up there. They’re not. It’s hard to think about all those numbers, I’m not as interested in it.

**Shanel:** If math isn’t one of your favorites [subjects] then you aren’t going to be very good at it. If writing and English was a favorite [subject] you would be good at that. Like, I would say I'm a 6 in Math and a 9 in English.
In these three pre-interview examples, it is apparent that the students had a mediocre perception of their own interest in mathematics and shared a similar belief about their mathematical abilities. All three students explain that mathematics is something they are not interested in and in fact, they find difficult. Dash explains that mathematics class is boring, and Shanel said that she would have a higher self-efficacy if it were a course she was interested in.

As these students progressed through the SSJY program, it became apparent that their interest in mathematics increased and they developed a stronger belief in their own mathematical abilities. These students indicated that their interest is connected to their beliefs about their ability in mathematics.

**Dash:** I’m a nine. It depends on the kind of math class. If there is a particular problem to try to figure out, like an urban planning problem, it’s interesting. [Then] I can do better with that math.

**Samantha:** Like a six, it’s not that great. Just because, like I said at the beginning, I’m not so good at math. Math is my greatest struggle, but I learned here that it can be fun, [and] it’s better that way.

**Shanel:** I’m at an 8 for math. Math in real-life, like in SSJY gets you into it because it's where you live and it matters. Math becomes more interesting that way.

Dash’s beliefs about mathematical ability shifted from a seven to a nine; he believes that mathematics can be interesting, if put in meaningful contexts, thus showing an increase in his beliefs of his own mathematical ability. Shanel and Samantha experienced similar outcomes. They learned that when mathematics is contextualized, it is interesting and their confidence in mathematics improves.

The data also revealed that, for many students, failure in mathematics became a self-fulfilling prophecy. The excerpts below describe how students’ self-doubts greatly affected their mathematical ability, leading to stress, lack of interest, and eventually, failure in mathematics.
performance. The participants expressed the relevance of this outcome as follows: when people do not believe in their own ability or have high expectations, they do not try. This is illustrated below.

**Mercedes:** I would say a seven. I actually like math; I am just not good at it. I don’t know if that will ever change.

**Gio:** Seven, because sometimes I will get confused on the problem. [For example], the first thing I said in my head I will think it’s correct but I will change my mind and go to my second answer. So my first answer will always be correct but instead of using my first answer, I’ll use my second answer; so, it’s kind of wrong. I feel like I can always be wrong [when] I second-guess myself.

When these students were asked about their confidence in their ability to do mathematics after participating in the SSJY program, they acknowledged that they saw important connections between mathematics and the problems they observed in their local neighborhoods. They also expressed greater beliefs in their own ability to use the mathematics that these problems require. To explain their mathematical ability they provided examples that involved activities of the SSJY, showing an increase in their confidence over time.

**Mercedes:** Nine, because some things I would kind of forget and I would kind of get the answer wrong; but some things are really easy and it comes off the bat like I know how to do it and like it. I am good at math when I’m here at [SSJY]

**Gio:** Eight, because sometimes I have problems with math, when the problem too hard or stuff; it takes me longer to get the answer. Around eight, yeah, but, I feel like I am getting better at it.

It is clear that both Mercedes’s and Gio’s beliefs about their mathematical abilities improved with regard to the mathematical work they completed in the SSJY program. According to Mercedes, her beliefs in her own mathematical ability changed from a seven to a nine, and she attributed this shift to doing mathematics in situations that she enjoyed while participating in the SSJY program.
In similar situations, students thinking about what counts as mathematics changed during the interview discussions. Most students discussed their mathematical ability in terms of what is learned in mathematics classes in school. However, as the program progressed, this definition changed to include what was being learned in the SSJY program as well. In the two excerpts below, Jo discussed her mathematics ability in terms of the grades she received in school, while Jerry discussed how well he performed in mathematics class.

**Jo:** Eight, because I’m really really good at math…Cause right now I have an A. If you give me a problem I haven’t seen before, then I won’t know how to do those unless you show me

**Jerry:** Seven, well, mostly the math classes I’ve had I’ve done pretty well in.

However, in the post interviews, these beliefs changed:

**Jo:** Ten, because when it comes to those line graphs where you have to…some of the equations on the line graphs I sometimes forget about how to do those and I have to be reminded how to do the equations.

**Jerry:** I am an eight, because typically even if I don’t know the exact method of how to solve a question, I may be able to do it on my own in my own way. Because when I understand the math I do very good on it, and I can work my way around it to problem solve when there are real-world problems like here [SSJY].

These two students showed a positive shift in their beliefs about their own mathematical self-efficacy and a shift in their definition of what learning mathematics involved. Analyzing the interview data from pre-interview to post-interview indicated some increased self-efficacy in mathematics. The three common themes included an increase of interest in mathematics in a meaningful context, familiarity with the urban planning process and a shift from thinking of mathematics as learned only in classrooms to considering mathematics as something that can be applied outside of school.

**Cognitive Domain**
The cognitive domain represents the emergence of students’ mathematical thinking and understanding. Students were asked to rate their understanding of mathematics in either writing about or presenting graphical data. Students discussed their lack of comfort and understanding of the mathematics embedded in the real-world context. The students’ self-reports indicated discomfort under the pressure to explain the material accurately.

**Jaleesa:** Seven, cause I get it but it’s not telling me a lot. It’s just what areas the temperatures are different.

**Julio:** I am not sure about these graphs. I’ve seen them, but I’m not sure if I’d want to take the time to do it. If I was in school and had to, I guess I should.

**Jerry:** Depends on how much I understand it. If I understand it fully, I’ll be perfectly fine. If I don’t understand it, then maybe an eight or maybe a seven.

As these excerpts illustrate, during the pre-interview all three students showed tentativeness about the material being learned, which may have led to uncertainty in their own mathematical abilities. Over time there was a shift in this thinking as noted below.

**Jaleesa:** Nine, because I’m getting better at writing about stuff like graphs and data and observing different things about other stuff.

**Julio:** Mathematics is about working hard but you also need to know your stuff so that you have something to work hard with.

**Jerry:** Probably ten. I feel like I understand the data that’s contributing to the graph. To explain it to someone, I would have to understand it. Seeing this graph, I understand it; therefore, I think I would feel comfortable explaining it because it’s simple I guess. At this point, I find it very simple and I understand it.

Since the data and graphs were inaccessible to the students when they first encountered them, they were not confident about their ability to interpret these data and graphs. However, after learning more about the graphs and how they could be used to make decisions for urban planning projects, the students’ level of comfort and overall cognitive self-efficacy improved.
The students agreed that working hard and having mathematical knowledge was as important as having the ability to strategize and discuss the interpretation of the graphical data.

As students learned more about graph and data representation, they become more interested in the material. Once they knew more about graphical data and how to make appropriate interpretations, they suggested that they would feel better about discussing and writing about graphs.

Andy: Um, I’d say a six, because at the same time I do know a little bit about this but I wouldn’t want to teach anybody and give them false information. Like I don’t mind teaching at all or telling anybody or explaining anything but if I have the wrong information then I just don’t want to do it because then I’m going to be passing on more wrong information.

Samantha: A six. Not so comfortable. Because I would be very shy to explain this graph now knowing how to say it the right way. I’d feel not so comfortable, because I wouldn’t know if I would put the right or wrong answer.

The consistent engagement in the project activities provided students with experiences that included graphical representations, specifically regarding how to make appropriate interpretations of the data. These learning experiences may have helped students develop a stronger and more positive view about their mathematical abilities.

Andy: I would be pretty comfortable. I would be a ten, because now I’m really used to getting up and public speaking. I’m completely broke in that factor so it’s no problem for me. I would love to give it a shot and explain it to the class. I would love to give it a try.

Samantha: Eight. I’m kind of nervous. But I am so much more comfortable and can explain it to the teachers and do a good presentation.

In these examples, both Andy and Samantha indicated a new level of comfort with the graphs, and they were convinced that they were able to explain the material to others based on their own interpretation and understanding.
The students’ post interview responses show that the shift in their attitudes about mathematics is a result of tensions that arise when they are asked to extend school learning to real-world situations. Before the program, they thought of mathematics as something that only happened in school. The SSJY program challenged students to change this attitude about mathematics. For example, in terms of the affective domain, the students’ beliefs about their self-efficacy and capacity to learn mathematics improved. There is also an increase in self-esteem and perceived status as mathematics learners, mathematical understanding, and confidence to succeed in this context.

**Conative Domain**

Conation includes students’ dispositions toward learning, actions taken to learn and the strategies they employ in support of their learning (Eynde, et al., 2002; Tait–McCutcheon, 2008). It includes their predilection to mindfulness and reflection as well as their inclination to plan, monitor, and evaluate their work and. During the interview process, students reflected on their urban planning experiences with the interpretation of the graphs created by CommunityViz.

**Gio:** I think I’m a five because I’m not good at graphs because that’s not one of my favorite things to do, so I have a different type of weakness in math. Graph is one of them; I don’t like using graphs that much but I can use them. I like figuring out ... instead of a graph.

**Dash:** I don’t even know. It’s a lot of work to do these graphs. You have to remember a lot of stuff to get it right. Maybe I’m a 4?

Reflecting on his experiences in mathematics, Gio noted that he has weaknesses in mathematics that were areas of concern, and as a result he does not have a high level of self-efficacy in terms of understanding the graphs. Dash possessed a similar reticence and was overwhelmed by the prospect of interpreting the graphs and making urban planning decisions.
However, after involvement in the SSJY program, both students expressed greater confidence in interpreting the graphs and a more thorough understanding of the mathematical concepts involved in this kind of interpretation.

**Gio:** An eight because I like graphs better now. When I first learned them, I didn’t like them because I didn’t get them. As we learned more, and I saw they were helpful, I started to like them better. I’m ok in graphs now, when I do temperatures and stuff.

**Dash:** Definitely a 7. You want to make good decisions for the site. You need to think back to all the different graphs that you have, or that you made and use them to help. It all comes together then.

As both Gio and Dash participated in more SSJY program activities involving graphical data, their thinking about mathematics problems started to shift in a positive direction. Initially, they showed no interest in graphs as they noted that interpreting graphs was a weakness. It was easier for them to skip those questions and move on to the questions that did not involve graphs. However, as the SSJY program progressed, both students admitted that using graphs as an interpretive tool to assist with making urban planning decisions helped them (a) develop a more positive attitude, (b) increase their interest in graphs in particular and, (c) strengthen beliefs in their mathematical ability.

In terms of self-efficacy, Bandura (1986) believed in the existence of three psychological domains of functioning: the affective, cognitive and conative. The students’ responses to questions involving the affective domain indicated a robust relationship between interest and success in mathematics. The students interviewed believed that real-world meaningful mathematics problems were interesting and purposeful, and as a result they would work harder to find a solution. The interviews indicated the students had an increased belief in their mathematical ability. Analyzing the questions from the cognitive domain indicated that hard work and familiarity with the material led to a stronger understanding of mathematical concepts.
Once many of the students had developed this stronger understanding, they became more confident in their own mathematical abilities. In terms of the conative domain, reflecting on their work and how certain types of mathematics (interpreting graphs) can be used to solve problems, students’ beliefs about their abilities to interpret the graphs improved.

Mathematical Understanding of Graphical Interpretations

Developing pedagogies and instructional tools to support learning mathematics with understanding is a core goal in mathematics education. This section explores mathematical understanding of interpreting graphs from real-world data, using urban planning software as a mediating tool. The goal is to examine the insights into mathematical understanding that the ten students provided through their experiences in the SSJY urban planning project. The analysis of data presented in this section answers the over-arching research question:

How does involving high school students participating in SSJY urban planning projects in their neighborhoods create meaningful contextual problems that influence their mathematical understanding of statistical representations?

This section on mathematical understanding is organized into three strands. The first strand centered on the connection among multiple-realizations of a mathematical concept encapsulated in various forms of graphical and symbolic artifacts, which is considered to be an important indicator of deep understanding of that subject matter. The second strand that characterizes mathematical understanding involves constructing relations among mathematical facts, procedures, and ideas. The third and final strand highlights students’ ability to reflect and communicate a rationale for mathematical problems, indicating broad links between mathematical concepts and the questions that they are asked to answer.
Each sub-section is organized to encapsulate the main research question by examining students’ baseline understanding of mathematics in real-world settings prior to the intervention program. Additionally, there is an exploration of mathematical understanding during the urban planning process, which includes information from students’ final presentations and post-interviews. Each of the three categories will focus on one case study taken from the cohort, with responses and artifacts from the other seven students supporting the results.

**Multiple Realizations of Student Collected Data**

“That graph doesn’t even look like our site, I don’t get it”

Since the launch of the urban planning program, it became evident that students struggled to understand the data that was collected prior to the development of this study (DeBay, et al., 2012). Initially, only a few students understood how the graphs created through Excel or CommunityViz could relate the data to the vacant lots studied in person. These few possessed the ability to look at data collected on a piece of paper, compare it to a table representing the same data, translate it into a graph and then eventually make urban planning decisions. However, many students struggled to understand how the different components of the collected data were connected. This barrier existed due to the lack of understanding between real-life situations and how they are visualized in different mathematical forms such as tables, charts, and graphs (Lapp & Cyrus, 2000; Leinhardt, et al., 1990). This section explores students’ understanding of different visualizations of the data. Two student cases are presented and discussed in order to illustrate students’ mathematical understanding and to make sense of their progression over the course of the project.
Real-world mathematics prior to SSJY. Before Dash’s introduction to the urban planning project, he felt that his mathematical understanding and experiences in mathematics were solely tied to the work that he was doing in his mathematics classroom. In order for Dash to succeed in mathematics, he sought out external support for the courses he took (i.e. extra help, lots of exercises to practice). However, when prompted to discuss mathematical experiences outside of the classroom, he mostly mentioned using money in social situations.

Dash: Math happens a lot in the world. Like when I go out to restaurants, how many people are there, how much the bill is, and how much each person’s supposed to give for the tip. Also, if I’m buying something or if someone gave me like a hundred dollars and they tell me I’m supposed to spend a certain amount, then I use math to control my budget. Mostly money I guess.

Although Dash was involved in an advanced calculus course at the time of this interview, it was evident that for him applying mathematics outside of the classroom generally involved understanding how to pay for things and calculate percentages. Despite his course load, it was evident he was not successful using mathematics in other situations. Julio, when asked the same question during his interview question, echoed this perspective:

Julio: When I go with my mother to [shop for] groceries, we try to figure out what to buy, what not to buy and what brands are expensive, what ones are not expensive; so, we have to do the math so it can be matched up to one-hundred dollars.

For Julio and his family, mathematics was related to staying within a budget and deciding what brands they could afford on a grocery-shopping trip. In the cases of both Dash and Julio, when the question was re-worded to reflect different ways in which mathematics can be expressed in or out of the classroom, they were unable to articulate other ways of using mathematics in the real world.
Mathematical understanding prior to SSJY. Prior to Dash’s involvement in the urban planning project, an excel graph similar to Figure 5.1 was shown and he was asked to discuss both what he was observed from the graph and possible reasons for creating this type of graph.

Figure 5.1. Example of Dash’ Surface graphs in Excel

Although Dash was able to grasp concepts fairly quickly throughout the project, this was a new type of graph for him and he struggled in the beginning:

Dash: Well it shows us temperature I think? I mean, it’s like ten or so, fifteen or eighteen degrees? What do the bumps and points mean? I don’t know.

Dash showed the ability to read the graph title and extrapolate information from the axis titles, but was not able to make the connection among the graphs, the physical site, and what a point on the graph would mean compared to a point on the vacant lot. In addition, Dash was not able to make sense of the legend, which might explain why he could not describe how the various parts of the graph were related to each other. He was not successful in interpreting the data represented on the graph. Similarly, Julio had a basic understanding of the graph that was slightly better than Dash’s understanding. He was able to explain what some of the high and low points would mean in relationship to the site. However, his explanation showed a very elementary understanding of what the graph meant.
**Julio:** It shows that the temps that are here, red is up to ten and twenty in Celsius, and green is twenty to thirty in Celsius. Not sure what to do with that or how it relates to what we collected?

Julio’s comment revealed that he understood what a high and low point on the graph would mean; however, he was not able to discuss how data displayed in the graph related to the vacant lot that they had visited the day before. Furthermore, he could not articulate what the graph had to do with urban planning. The goal of these interview questions was to determine whether students understood the relationship between the vacant lot they previously visited and the data collected at the site, which was displayed in tables and graphs. These multiple representations of data were used to symbolize, describe and refer to the same mathematical entity - the scientific data collected from the site. Initially, many of the students, including Dash and Julio, did not make these connections. As the project progressed, there were several times when Dash was observed moving back and forth between the data gathered at the site and the graphs constructed from that data.

**Dash:** Every time you made a design decision when you're creating a new design, the computer calculates a whole bunch of graphs like this, based on national decisions. So my own scenario, I make a decision and go to the graph. I can see how the picture relates to the graph and helps me make a decision about what to do next. Did it make the design better? Then I'll keep it, if not I'll go back and change it and go back to the graphs. Find the best site.

Making connections among urban planning decisions, maps and the graphs that were created, helped the students choose what types of buildings would work best on the urban planning site. Dash was able to take the different visualizations of the data and construct meaning in order to make decisions about his redesign of his vacant lot.


**Students’ Discussions of Real-World Mathematics**

As the urban planning project came to an end, both Dash and Julio were interviewed again to explore their understanding of interpreting graphs in the urban planning project. When asked about mathematics outside of the classroom, Dash initially talked about mathematics and money (as he had at the beginning of the study), admitting that since using money involves mathematics, then you use mathematics every day.

**Dash:** [You use money a] lot when you buy something, when you give change. If you’re trying to give people money, you have to know how much money you have in your bank account; so you use math every day pretty much.

He paused. Then Dash continued stating,

We use math in [SSJY] for like temperatures, and yeah, when you’re trying to look for the temperature of surface, temp air, air temp, and all different types of temperature. Temperature matters when you do urban planning. I want to put an ice cream stand where it’s hot. More people would want to cool down with ice cream. That point on the graph means it’s the hottest, that’s where I’d put an ice cream place.

Dash had reached a level of understanding that using graphs in urban planning was in fact mathematics and that this type of mathematics could be used to help solve real-world problems. Overtime, Julio reached this level of understanding as well. Mathematics applied to activities outside of the formal classroom had been expanded to work done in the SSJY program. Julio illustrates this perspective in the following statement:

**Julio:** Say my family decides to go to Six Flags and there are a lot of us, we have to divide ourselves to, how many cars we can fit into, how many people, that type of thing. We do a lot of math and graphs at SSJY, and that’s it, and in a sort of way we have to figure out the cost of the buildings and the analyzing, and not the analyzing but the assumptions that we have to lower the price and how much a bigger difference it was, so
yeah, math is used a lot outside, you need it to do a good job at urban planning.

As the SSJY program progressed, both Dash and Julio showed signs that they had developed a stronger understanding of how to interpret graphs, which included making appropriate mathematical connections to multiple representations of the data. Using the various representation and visualizations to make effective trade-offs that allowed the students to function as urban planners in which the end results were they were capable of constructing the best possible design for the vacant lot. Not only could Dash give a more thorough description of the data, he was able to collect the data and display it in tables; then he successfully used the data to develop graphs, which assisted him in making reasonable interpretations of the graphs and use the information generated to make important urban planning decisions. Dash provided this explanation.

The graph’s giving us a range from about eighteen to less than thirty, thirty, well twenty-five-ish or something like that, and it’s telling us the length of a park from zero to ten feet. The scale, well the range for the temperature is from zero to forty degrees Celsius. This can be seen in my decisions on my buildings that I created in that CommunityViz program. See, I put an ice cream shop there because the temperature was hot, people will get hot and want something cold. Easy money.

Julio’s comment resonated with Dash’s earlier explanation of ?, whereby he explained, “I guess it tells us, it was in the morning, and then as the hours goes on, the temperature raises, you know, because in the morning it’s not that bad, but when it goes up in the middle of the day the temperatures [will be higher].

When actually creating the re-design of the site, Dash considered his comments about energy use and temperature when deciding what type of park to build. This was taken into
consideration when Dash was figuring out what to build. He created the graph presented in Figure 5.2 using CommunityViz.

![Energy Use Graph](image)

**Figure 5.2. Dash’s Energy Use Graph**

Dash provided this explanation of the graph, stating:

If you want to find out the temperature of a certain area, it could mean a lot for the energy use in the park. If it’s too warm, it could mean that you would have to use more energy to cool it down in that area. Like, if there are a lot of plants, it needs a certain temperature to live. Like, the residential has a lot of parks too, so the hot areas won’t use so much energy. But it’s hot there, look how much energy the buildings will use. It’s so much higher than the residential.

Dash’s explanation of the graph illustrates several key elements about the development of his mathematical understanding of graphical data. First, he is able to use the data displayed in the graph to make comparisons between the amount of energy required for a residential site and commercial site. For example, when examining the data, he realized that the residential site would require and use less energy than the commercial site because the residential site had parks in that area, which was not the case for the commercial site. Second, he was able to make informed decisions about the type of design that would be appropriate for the site. In making urban planning decisions, he considered the energy use data that represented the heat at the site,
concluding that it made more sense to create a residential site that required less energy. Overall, Dash’s understanding of what the graphical data represented helped him make sense of the data and assisted him in developing an appropriate plan, which modeled effective use of the vacant lot. In effect, Dash was working like a real urban planner or designer.

Placing data in the context of urban planning made the process relevant for the students because of its real-world focus and the variability of the data itself. Furthermore, the manipulation of the data from being displayed in a table to being used to construct a graph helped the students make adequate interpretations that they understood.

**Technology mediating multiple realizations.** An important aspect of this SSJY urban planning program was exactly how the technology mediated the mathematical understanding. In a discussion of how the understanding of graphs was facilitated during the urban planning project, Julio explained,

> I learned a lot about technology here at [SSJY]. Like with the air temp, you know the time we went on a field trip and we did science with the air temp, Celsius and stuff like that. I learned a little bit more about that and a little bit more about technology, how we’re going to analyze this, the humidity of this and edit, and put in the pictures right there. I learned a lot with CommunityViz. It helped me understand numbers, then graphs, then how to make decisions.

It is important to note that the effectiveness of technological tools assisted the students in developing their mathematical understanding of graphical data. For example, when students were asked what would help with their understanding of the data displayed in graphs, it became common for students such as Julio, to suggest that the use of software like CommunityViz helped them with the urban planning process and with understanding the data.
Interrelated mathematical connections. In the cases of Dash and Julio, there was a distinct connection between their understandings of the multiple realizations of the data to their ability to make urban planning decisions. However, there were also students who were specifically able to illustrate their understanding by making connections to the vacant lots and the graphs. In one scenario, Jaleesa successfully linked the concepts of both multiple realizations and making connections. When first asked about an Excel temperature graph, Jaleesa noticed that the graph was a visual representation of the same data that was collected from the site. Specifically stating, “Oh, this graph is just to show our tables in a different kind of way. It’s just better as a graph. See, that high point on the graph is where the sun was beating down in the middle of the park.”

When she first entered the program, Jaleesa noticed how the multiple realizations connected to the site. This feature was observed as students worked on a number of components of the project. For example, while working on her site, Jaleesa declared,

See, it depends on what you’re going to do with the park. Say if somebody wanted to build something on there at the high point of the graph, they wouldn’t want to build something for people to walk on because it looks like the temperature is kind of high, or if you were going to build something, you probably put something that has to do with water so the ground wouldn’t be as hot as it seems to be.

Not only was Jaleesa able to understand the different visualizations, she was also able to make connections between the vacant lots, the data collected and the graphs. The multiple representations including the graphs and diagrams, tables, symbols, and maps from this project were the thinking tools for doing mathematics specifically in this urban planning context. These tools were important to helping students make many of the urban planning decisions throughout the SSJY program.
Constructing Relationships

According to Carpenter (1997), unless instruction helps students build on their own informal knowledge and relate the mathematics they learn in school to it, they are likely to develop two separate systems of mathematical knowledge: one they use in school and one they use outside of school. Making these connections was central for students if they were to use the important mathematical skills that they were learning. During the urban planning project, exploring students’ mathematical understanding as they constructed relationships between their understandings of graphs they created and how those graphs were used to make urban planning decisions provided essential information regarding how students used data to construct meaning from different mathematical relationships. Both Andy and Jerry highlight this occurrence throughout the urban planning project.

As mentioned earlier, while participating in this urban planning project, high school sophomore Andy was an African American male from a working- to lower-middle class socioeconomic status with parents from limited educational backgrounds. In conversations and interviews about using mathematics outside of his high school classroom, Andy described examples of both how mathematics applies to music. For instance, in preparation for a field site investigation, Andy readily answered questions about out-of-school mathematics while working on his project.

Um, I do use math when it comes to my music. When I’m playing the piano, I usually use numbers to memorize where each key is. So like, instead of A through G, I have one through six and [for] the black keys on top I have them as halves so I can remember them easily as well.

When asked about mathematics learned at SSJY Andy gave a very quick response.
Here at [SSJY] I don’t know about that. Maybe in the current class that I’m in now where I’m using the graphs and stuff; I suppose that would be influenced with the math because I have to learn how to figure out the distance between our current location that we’re studying now and where something that’s not really there is outside of it.

Andy’s partner Jerry was listening to the conversation and decided to give his thoughts about mathematics outside of school. Like many others in the SSJY program, Jerry’s explanation of using mathematics outside of school involved examples of using money. For example, Jerry stated:

Outside of school, well, when I’m bored, I like to figure out if I want to make $200,000 a year, how much would I get paid an hour. Then I just pop in numbers like for example 50 dollars an hour for work, if I work 7 hours a day I multiply by seven, five days a week I multiply that by five then multiply by four, then calculate how much that would be a year.

Jerry did not initially believe that the SSJY program activities in which students were participating involved mathematics. He was looking forward to see how mathematics could apply to the real world that went beyond the application of activities involving money. Both Andy and Jerry did have prior knowledge involving connecting mathematics to their daily lives, however, at the high school level, the mathematics that they learned was more complicated than notes on a music scale as well as financial transactions. Their mathematical understanding of the connection of mathematics and the real world before the program started was at a basic level.

During an interview for this study, Andy was asked to describe and explain why someone would make a surface graph for the urban planning project. Early during the program, Andy’s description was vague and uncertain. He stated, “Um, I’m guessing this graph is representing the length of the park that is going to be and the size and the temperature in certain points that is on this graph. That’s what I estimate.” Andy was able to provide very vague explanations of the graphs, reading the title and the axes to make sense of what was being asked of him. He was not
able to explain why these types of graphs might be needed for urban planning. His SSJY partner Jerry gave a similar answer. However, Jerry provided more details in his description of the graph, giving specifics about temperature. Jerry explained, “It’s telling the temperature and the length of the park. It’s showing the temperatures in a specific location in the park. Every location has a specific temperature. For example, the edges seem to be cooler as opposed to the center of the park.”

As the SSJY program progressed, Andy redesigned his park to have residential components. There were two major apartment complexes with many areas that contained trees and parks for people to socialize as illustrated in Figure 5.3

![Figure 5.3. Residential redesign created by Andy.](image)

Although he had created two different designs for his park in which the other was a commercial park with many stores and a movie theatre, he believed that the residential site with
a park area was a better investment. Using the CommunityViz software to generate the graphs assisted him in reaching this conclusion. When comparing the cost of both of the sites modeled in Figure 5.4, Andy explained why the commercial site was better, stating, “Although both the commercial and the residential sites were over the budget, you can see from the graph that there is a difference of about $12,000,000, the residential is cheaper for sure.”

During the final presentation for the redesign of the vacant lot, Andy included the graphs illustrated in Figure 5.4. However, he included two more graphs to make his case for his plan. He used the graphs in Figure 5.5 pointing out that not only did the residential site cost less; it had a comparatively insignificant energy-use compared to the commercial site use of energy.

Figure 5.4. A comparison of the total cost of the commercial (left) and residential (right) redesign of the park.

Figure 5.5. Graph showing energy use for both the residential and commercial use of the park.
After their final presentations, Andy and Jerry were interviewed and asked questions about their understanding of the graphs and how mathematics is used outside of the classroom. Compared to Andy’s initial beliefs about mathematics outside of the mathematics class, Andy provided a description of how mathematics in the real-world that included more than simply an example involving music; instead his description focused on sports. He stated, “Like sometimes when I’m like playing catch or something, like playing football, I would measure out the distance between the other guy and me, before I throw the football, so I can see how much strength I have to put into the football before throwing it.” This description was not the only example he provided. He also used examples from the SSJY to discuss real-world mathematics. Andy further explained,

Mainly, when we’re trying to figure out the total surface area within our site and finding certain distances between one point and another in a certain area. For example, that street we had trouble parking on, like how narrow it was, and I tried to measure the little opening there we were trying to get into; so, we can see how wide we can have a certain opening so that we can have the parking lot there and stuff like that on the site I’m working on. We’re doing research on different sites to make a good estimate on what the actual price for … planting trees in Boston residential or commercial buildings.

Andy described how mathematical concepts such as surface area and distance helped him decide how parking can be used in the redesign of his vacant lot. This indicated that he made a connection between these two mathematical concepts (surface area and distance) to make a decision in his real-world redesign of the site. He also believed that using mathematical information from the graphs was a way to research the costs of the buildings and gardens depending if the redesign had a residential or commercial focus.
Similarly, Jerry used examples of graphs as a tool for decision making to connect the data that were collected to concepts such as surface area and multiplication to make decisions about the urban planning project. Jerry gave this explanation, stating, “The work at [SSJY] is mostly statistics. Like just how I was in the room I did, they were giving me square feet and the cost for it and depending on the square footage of a building, and you multiply that by the cost. For one square foot, just multiply those two numbers to get the total cost for, say 1000 square feet.”

When prompted to discuss the graphs that were created, Jerry again likened them to statistics:

The edges seem to be the coolest, center is the hottest, and toward the middle around the center is in between. From what we see in the graph, this is a very warm area, we can possibly put a pool there. I see the residential is the highest...the Commercial is the lowest out of all three scenarios, and in the Custom scenario it’s in the middle but still significantly lower than the residential in terms of cost? It’ll depend on what the mission is. If I’m trying to provide homes, than the residential would be best despite the fact that it costs the most. That’s the mission to complete.

**Technology mediating the construction of relationships.** For some students, it was a difficult task to make sense of the data collected from the vacant lot and connect it to graphs that would eventually assist them in making urban planning decisions. However, when asked what helped mediate the discussion, many students including Jerry, agreed that using the urban planning software to make a decision about the urban planning process and then have the ability to see (in real time) how their decisions changed cost, energy emissions, jobs, etc. allowed them to develop a better understanding of what would be ‘good’ decisions to make as urban planners. This point is evidenced in Jerry’s comments. He stated:

I really liked learning to use the software Community[Viz]. It’s been helpful. I never have had experiences with software like this before. I find it very valuable. It makes the math easier to understand. I can build a house, go to and understand the graph, and see if
it changes for the better, if I put up a different graph.

Again, by the end of SSJY both Jerry and Andy showed that making connections to what they know about the neighborhood and the data collected can create meaning for urban planners by relating the different types of representations together in order to make decisions. This was apparent in the explanation of mathematical uses of graphs in the SSJY program as illustrated in Andy and Jerry’s comments.

**Andy:** Well it, I believe that this graph is showing us the temperature of a park, actually, like the total surface area or surface temperature of that park, and it’s measured from zero degrees Celsius to forty degrees Celsius. This is helpful to make urban planning decisions. Like don’t put a park bench where one of the high temperature peaks happen. That’s what the graph helps us with.

**Jerry:** Total site cost of four different scenarios, one being residential, commercial, our own scenario, and uh, so basically there are three scenarios. So we can compare the three scenarios and determine which one is best for the urban planners. Helps me make decisions, for example what might be financially better or economically better.

In both cases, Jerry and Andy showed an increase in understanding of the connection between the physical sites they redesigned and the graphs created by CommunityViz. Jerry used high peaks on the temperature graphs to make a decision about where to put park benches, while Jerry examined at graphs to define total cost to determine which site was the most cost effective for an urban planner.

Samantha, a high school junior in her first year of SSJY expressed how technology assisted her in developing better mathematical understanding of graphic data, stating that technology was an important aspect of her growth in terms of mathematical knowledge. When she was putting together a final presentation, she reflected,
Technology wise, I’ve learned how to use PowerPoint and CommunityViz and how to find things easier on the Internet and math wise, I learned how to look at a graph better and understand what it’s trying to say. It will help tell the story when I have to present.

When prompted to discuss her mathematics understanding of how the graph tells a story, Samantha added,

When I'm working. Yeah. Here, like at [SSJY] when we use math here on the computers and stuff. Looking at the numbers on the graph, they help me make decisions like real urban planners. Seeing the graphs and the site and connecting it all, it makes it so much better when I talk about it in front of my friends or others.

When prompted, Samantha was able to discuss her experience with technology and how it helped her with urban planning. In particular, using the CommunityViz technology helped her make sense of the data collected. She was also able to connect the data to the project site, which facilitated her understanding of how to present the data. The ability to discuss and present mathematical concepts is the third idea of mathematical understanding; it shows that individuals can make connections across concepts and that they can articulate their mathematical thoughts about a topic.

**Reflection and Communication**

Communication is an essential component of mathematics and mathematics education. It is a way of sharing ideas and clarifying understanding. Through communication, ideas become objects of reflection, discussion, refinement and amendment. The communication process also helps build meaning, permanence for ideas and makes them public. When students are engaged in challenging tasks that require them to think and reason about mathematical ideas and to communicate the results of their mathematical thinking to others orally or in writing, they learn to be concise and are able to persuade others to consider their ideas (NCTM, 2000).
Mercedes and Jo were two students that were very interested in being able to connect and explain the concepts that they were learning. When Mercedes first joined SSJY, she was asked about her experiences with mathematics outside of school. Mercedes replied,

When I’m in stores and I have to give them money and change and different things, and when I’m doing fundraisers. At church, I do fundraisers and bake sales and all those type of things; I have to use math to give them their change. In the church fundraisers, I have to talk about how I made the money. It’s important that I can talk to them about what happened, so they know where the money came from.

Jo in her explanation mentioned using mathematics outside of school and she did not see the activities she engaged in for SSJY as relating to mathematics. Jo stated, “Uh, basically when I have to calculate how much sugar I should put in the mixing bowl and things like that. So far in [SSJY] I’ve been doing science and technology, nothing that [about] math at all.”

One indicator for mathematical understanding of a specific task is the ability to explain the concept to another person or group. At the beginning of the urban planning project, Mercedes was able to provide limited information and to make a few interpretations of the graphical data. The quality of her understanding is evident in the following, where Mercedes stated, “The temperature average in this graph is about 20 degrees Celsius I believe. I can explain that much. But I don’t think I can say much more about it. I’d never be able to talk to others about this and have it make sense.” Early in the project, Jo could explain some of the graph, but was uncomfortable with explaining it to others. For example, Jo said, “Let’s see, x axis, y axis, temperature over here says Celsius. It measured. The length of the park is ten feet; basically this is the length of the park. I get it; I just don’t think I could tell others about it.”

As the SSJY urban planning program progressed, there were times that students were charged with presenting their most recent data for experience and fluency of presenting and
talking about their projects. In a PowerPoint presentation, Mercedes discussed the temperature in certain parts of the vacant lot. She explained,

So we had, uh, the main temperature of the area. As you can see, in the range of temperature was between 30 and 50 degrees, so it was pretty high that day. [Document scrolls down on screen] So, I said that it was between 30 and 50 degrees; there were different temperatures along the places so none of them stayed constant, they were either getting hotter or staying the same; distance and temperature were actually variables.

Three major things we noticed. The majority of the temperatures were around the forties, there was very little that we could do for a park in this area, it’s too hot. We could make a building with air conditioning.

She was very comfortable presenting and conveying the information that was used in the graph to her peers. An interesting point with respect to her presentation is that she was also able to take that data and make a connection to the urban planning project and use the data to make a decision about what should be placed in a certain part of the vacant lot.

It is not sufficient, however, to think of the development of understanding simply as appending new concepts and processes to existing knowledge. Long term, developing understanding involves more than simply connecting new knowledge to prior knowledge; it also involves the creation of rich, integrated knowledge structures. This structuring of knowledge is a key feature that makes learning with understanding generative. When knowledge is highly structured, new knowledge can be related to and incorporated into existing networks of knowledge rather than connected on an element-by-element basis. When students see a number of relationships among concepts and processes, they are more likely to recognize how their existing knowledge might be related to new situations. Once Mercedes and Jo improved their overall understanding of the mathematical concepts and graphs, they realized that it was easier to talk to others about the concepts, but also that it meant that they understood the concepts in a more complete way, which is illustrated the comment made by Mercedes.
With the site, the St. Patrick’s site that we’re doing, we have to actually calculate how much space we’re going to need and to obtain our goal or whatever, and the distances between a fire station and if we want to put one there, like if it would be right.

Similarly, when Jo discussed her experiences with graphs in SSJY, she elaborated, “Yeah in the graph stuff we use. That’s math, because we have to find the model of the graph and also describe the difference. Basically, we use it for comparing two graphs together, the difference between two graphs, so compare them.”

**Technology mediating communication.** During the students’ final presentations of the findings from each of the urban planning groups, many of the students believed that the technology was a powerful tool that assisted them with explaining the plans that they had created from the various data they gathered. For example, using the graphs as well as the three dimensional walk-throughs of the parks gave Mercedes the assistance necessary to properly explain the urban planning decisions that she made. Mercedes stated, “I learned how to use Community Base. That’s my favorite software. Yeah, and I like doing the 3D urban planning stuff; it’s like a SimCity type thing. This is great, because other kids will relate to that. I can use it to explain the hard concepts of urban planning.”

Over the course of their time in the SSJY program, Mercedes and Jo did not change their descriptions about the graphs significantly. However, they both demonstrated a new perspective of how to explain it to others so that they too could understand the concepts.

In one exploration of the importance of communication in mathematical understanding, there was a discussion between Mercedes and Jo, where Jo was confused with how to interpret a temperature graph:

**Jo:** So, I get the high part of the graph, but what does it mean for our assignment?
**Mercendes:** You see, that high point is where the highest temperature on the site is. Does this make sense?

**Jo:** Oh, so then we can answer the question right?

From this discussion, a tension emerged between what is shown on the graph and how you can use that information to solve problems that were given to the students. In this example, we see how the participant, Jo, struggles with this tension. After examining the graph created from the technology together, which is the tool, the participant decides that they can use that information to solve the problem. From the tension between both Jo and Mercedes, Jo obtains a strategy for explaining the graph and when they both went back to their computers, they gave the following responses.

**Mercendes:** The middle of the park is around thirty degrees Celsius it’s the highest temperature. Around the edges will be cold or chillier than in the middle because the graph has the colors that symbolize the temperatures. Maybe…the sunlight doesn’t reach there or there’s a lot of trees or buildings surrounding the outside that was blocking the sun from getting to that area. [This] will make you think about what to put where on the site. No park benches in the heat, ya know? We can all learn from this, the graphs connect to the places that we visited.

**Jo:** The highest temperature is between thirty and forty Celsius, and in the middle it is twenty to thirty degrees There’s no temperature lower than ten degrees. I use this info to look at different sites. The residential site costs more, the base scenario site costs less… I’d say this because it has enough money to put things that you need for your site and stuff like that and it’s enough. It’s not like going over your budget.

If students genuinely understand graphs or any mathematical concept at a level where they can explain and justify the properties that they are using and carry out calculations and make appropriate interpretations, then they are building a critical foundation of the mathematical concepts they are applying.
Interpretive Summary

This chapter focused on 10 urban high school students participating in an urban planning project. Students engaged in activities whereby they learned about the interpretation of graphs. Also, they were charged with redesigning vacant lots in their own neighborhoods mediated by professional urban planning software. Analysis of the data provided several insights into both increased student self-efficacy and mathematical understanding of interpreting graphical data.

Analysis of data provided insight into three different strands indicating that working with real-world, contextualized mathematics in the SSJY urban planning project affected the students’ self-efficacy. The first key finding is that students’ beliefs about their own mathematical ability directly relates to their interest in mathematics. Students believed that failure in mathematics is a self-fulfilling prophecy. Students believed that not knowing how to do something mathematically will lead to disinterest, apathy and eventually failure. This finding is consistent with Bandura’s Affective Domain of Social Cognitive Theory (1986) as it refers to emotional interpretations of mathematical knowledge. Students in the SSJY found that interpreting graphs in the urban planning project was more interesting than most mathematics they had been introduced to because solving problems in their own neighborhood was relevant. As students’ interest in the program developed, self-reported self-efficacy likewise increased in a positive manner.

Second, students felt pressured and discomforted when interpreting graphs in the early stage of the program. As a result, they felt a relatively low self-efficacy in terms of general mathematics as well as interpreting graphs. As the program progressed, there was growth in students’ process of coming to know and understand the mathematical tasks they experienced. This finding is consistent with Bandura’s Cognitive Domain (1986) where individuals can acquire cognitive skills and behavior by having more experiences with the task at hand as well as
observing the performance of others. Over the course of the SSJY urban planning project, students believed that learning more about the context of the urban planning project and using the graphs to make urban planning decisions helped them become comfortable with interpreting graphs, and as a result, they developed stronger self-efficacy.

The third and final strand for self-efficacy was a theme that exists within the auspices of the Conative Domain. This refers to the connection of knowledge and affect on behavior or action. Conation is necessary to explain how knowledge and emotion are translated into student behavior (Bandura, 1986). Students in the SSJY program were uncomfortable with interpreting graphs in the beginning, and as a result, when asked to make interpretations based on graphical data many chose to skip those questions or admit that they were not comfortable with those questions. However, with experience and working through the urban planning projects, many students noted that using the graphs assisted them with making urban planning decisions, and assisted with explaining their decisions to others as well as reflecting on their own decisions. As they engaged in these experiences, students’ beliefs in their own mathematical ability increased as well.

An additional significant construct examined during this project was how mathematical understanding of graphical interpretations was influenced by the SSJY real-world project as it was mediated by professional urban planning technologies. Three strands emerged that indicated that overall mathematical understanding increased.

The first strand involves students’ understanding connections between multiple realizations of the data that was collected (Hiebert, et al., 1997). Connections between interpreting graphs, their mathematical content, and how it relates to the urban planning project at hand, became an important feature of the project. Additionally, it served as an indication of
whether a student understood the data that was collected. Students in the program began to understand the different visualizations and to make connections between the vacant lots, the data collected and the graphs. These different visualizations became their thinking tools for doing mathematics in this context.

Students began to construct relationships from their own experiences as well as making connections between the problems they were solving and the mathematics skills necessary to solve the problems (Hiebert, et al., 1997). The second strand that emerged from the analysis of interviews, observations and student work, was students’ connections between the graphs that were created and the data from the physical vacant lot became stronger. This led them to a better understanding of the information and they were able to make informed decisions in their quest to develop quality-redesigned lots as urban planners.

The final strand that highlighted students’ mathematical understanding was their ability to communicate their mathematical thinking (Hiebert, et al., 1997). Students actively discussed how their approach to various problems became an important goal because it facilitated the entire group’s understanding of the urban planning decisions. For example, when students like Jo and Mercedes made their final presentations, they were able to explain and justify the graphs. Furthermore they use the information as evidence to support their reasoning for choosing one urban plan over another, illustrating a better of understanding of the urban planning process.
CHAPTER 6
SUMMARY, DISCUSSION AND IMPLICATIONS

This project investigated how a learning environment that involved students solving real-world meaningful problems, mediated by professional urban planning software, would facilitate a shift in students’ mathematical self-efficacy and understanding graphs. In order to explore this process, a multiple case study was conducted from 2011 to 2012. Although findings report only one bounded case, the deeply contextual data collected enables me to make conclusions which will hold across other studies of this nature. Findings indicate that the use of these real-world problems and mediating technologies precipitate a shift in the activity system, which in turn transforms traditional beliefs, leading to contradictions and consequently, ultimately effect changes in student mathematical self-efficacy and understanding. While these findings are not new and perhaps seem intuitive, the use of activity theory as a framework for tracking changes across an entire system - rather than merely tracking changes within the individual - is still a relatively novel approach when exploring at students’ interactions with technology.

This study explored the influence of real-life mathematical experiences and activities on high school students participating in the SSJY program. The overarching goal was to examine how professional urban planning technologies mediated students’ self-efficacy and interpretation of graphs. The students were charged with the task of using knowledge learned from their experiences with graphical data to assist them with making urban planning decisions that involved trade-offs of economic development and ecological opportunities. The following sections are presented in this chapter: synopsis of the study, importance of the project, a discussion of the findings, conclusions and implications, limitations of the study, recommendations for future research and final comments.
Synopsis of Study

The purpose of this project was to document student learning experiences in the context of solving urban planning problems in their own neighborhoods. The SSJY students collected and applied scientific data from vacant lots in their communities to inform decisions about redesigning existing spaces to benefit their neighborhood. Throughout this process, students created graphs using Microsoft Excel © or generated from CommunityViz urban planning software. Prior to this intervention, students struggled to interpret graphs and, as a result, students made uninformed decisions about their urban plans. A major goal of this project was to help students develop their mathematical understanding of graphs so that they could make informed decisions instead. Guiding the research for this study and the subsequent analysis was the following overarching question, which included two sub-questions.

1. How does involving SSJY high school students in real-world, meaningful mathematical urban planning projects in their own neighborhoods influence their mathematical understanding of graphical representations? In addition, the two of sub-questions addressed were:
   
   a. How does the implementation of GIS and EXCEL technology in the SSJY program influence self-efficacy as students interpret graphical representations of data?
   
   b. How is the mathematical understanding of graphical representations influenced by the introduction of GIS and EXCEL technology in the SSJY program?

This project assumed that involving these students in a meaningful mathematical problem, mediated by an urban planning technology, they would recognize and strengthen both their self-efficacy and mathematical understanding when interpreting graphs.
Importance of Study

An examination of the mathematics education literature suggests that although there has been research in both the use of educational technologies as well as using real-world mathematics examples that can assist with student learning, there has been little literature on how professional technologies mediate real-world mathematical problems, and more specifically, how both of these concepts together might influence urban student mathematical self-efficacy and understanding. This study argues that using professional urban planning software as a mediating tool to assist with solving real-world problems will augment student self-efficacy and mathematical understanding.

With a growing desire for students to become successful in STEM related fields, recent movements push to engage students in innovations in science, technology, engineering, and mathematics (STEM) education. This field is currently suffering from a major shortfall in both the number and the quality of young people studying and contemplating careers in STEM (NRC, 2007). Unfortunately, there are fewer urban students getting involved in STEM related fields than more affluent and successful students. Without the opportunity to learn mathematics in a way that is personally meaningful to them, many urban students voluntarily leave the STEM pipeline (NRC, 2007; Oakes, 1990). Not surprisingly, educational research is replete with data showing that urban students tend to develop negative attitudes towards mathematics and science, and are considerably less likely to select STEM-related professions as their future careers compared to students from other areas (Norman, Ault, Bentz, & Meskimen, 2001).

In response to this crisis, in 1989 the National Council of Teachers of Mathematics (NCTM, 1989) listed “Opportunity for all” as one of the “New Societal Goals” for mathematics education (pp. 3-4). These goals were re-iterated in the 2000 NCTM Standards (NCTM, 2000b). In fact, the NCTM Equity Principle states, “Excellence in mathematics education requires
equity—high expectations and strong support for all students” (p. 12). It is paramount to recognize that denying students access to an advanced mathematics education is tantamount to denying them their civil rights; therefore, achieving mathematical equity for all students demands activism on the part of all stakeholders in children’s education.

The reform movements of national organizations such as NCTM as well as the CCSSM attest to the importance of equity and social justice in mathematics education. According to NCTM, the need for reform is often emphasized in discussions regarding mathematical literacy requirements of the future workforce of the U.S. economy. Helping students become mathematically literate workers was one of the goals stated in the NCTM Standards (NCTM, 1989, p. 3). Continuing research on how to improve students’ confidence as well as their understanding will only lead to more students, specifically from urban areas, becoming involved in STEM related fields.

A second notable area of research is the use of professional technologies to assist students with solving problems. Many teachers and non-technology oriented professional mathematics educators alike often have a narrow view of what it means to incorporate technology into the mathematics curriculum. This view limits the use of computers to computation only, a skill students in the past managed to master without any technological support (Cuban, 2001). Using professional technologies in classrooms can stimulate mathematical exploration, engaging students in investigation, encouraging them to conjecture and test their conjectures, and exposing them to the intrinsic beauty of mathematics with all its rich connections. Using GIS in the classroom addresses many of the CCSSM standards, such as using appropriate tools like GIS, constructing viable arguments using GIS data, and creating mathematical models to solve real-world problems.
Discussion of Findings

This project offers insights about learning from the perspectives of ten urban high school students. Operating within an activity theory (AT) framework, this study illustrates how both self-efficacy and mathematical understanding mediated by technology are shaped by tensions among the object, rules, division of labor, community and subject of the SSJY activity system. Thus, the conclusions of this study were based on said assumptions and findings about students’ self-efficacy and mathematical understanding.

Self-Efficacy as a Nested Activity

The survey results from Chapter Four indicated an increase in students’ self-efficacy with respect to interpreting graphs from the beginning of the SSJY to its completion. This follows other research that indicates that as mathematics content becomes more challenging in high school, those with a more positive experience are more likely to succeed (Saxe & Esmonde, 2005; Tait–McCutcheon, 2008). In terms of students’ technological self-efficacy, pre- and post-surveys about technological self-efficacy with the use of professional urban planning technologies were administered during the beginning and end of students’ involvement with the Urban Planning Project (Compeau & Higgins, 1995). To provide further insight about the findings from the survey data, the remainder of this section discusses the findings through a nested activity lens.

The activity system. Learning activities are embedded within larger activity systems (in this case the SSJY program level). Self-efficacy as a construct is difficult to observe moment-by-moment, and therefore involves exploring students’ beliefs over a period of time. Hence, the uncertainty about where one snapshot of an activity begins and ends. This uncertainty about boundaries is observed by explaining an overarching activity system as a nested activity: “An
activity system is made up of nested activities and actions all of which could be conceived of as separate activity systems or other instances of the same system depending on one’s perspective” (Barab, et al., 2002, p. 79). In response to this complexity, it should be recognized that a case study, which uses an activity system as the unit of analysis, cannot be a fixed entity with rigid boundaries, but rather must be a permeable and flexible frame of reference.

**Discussion.** Findings from the case studies were used to extend the discussion about the relationships between the students’ use of urban planning technologies in the SSJY program and student self-efficacy as they interpret graphs. Findings were presented from the perspective of Bandura’s Social Cognitive Theory (Bandura, 1977, 1986). What follows is a discussion about the development of students’ self-efficacy, which is examined from the affective, cognitive and conative domains (Eynde, et al., 2002; Tait–McCutcheon, 2008). Figure 6.1 represents the activity system. Throughout the process the relationships among all aspects of the activity theory model proved to be more fluid than the constraints of the known Activity Theory Triangle. As a result, the discussion will be explained through a more fluid design as below in Figure 6.1.

*Figure 6.1. Urban Planning Project Activity System.*
Object. It is extremely difficult to pinpoint the object of an activity system, as it shifts dynamically while it is being acted upon. However, it is possible to discern objects in both the video data and the interview data. The following discussion highlights some of the observations while the students were using CommunityViz to redesign their parks. We can see that the object of the urban planning project initially became computer use itself, rather than the development of critical questioning skills. Using the urban planning technology and working through real-world problems that the students found meaningful influenced their personal development. These factors positively affected the students’ confidence in their own mathematical ability, which spilled over into their personal life. A further object emerging from the data is motivation. In this instance, the technology and real-world connections acted on students' motivation. As motivation is necessary for learning, one could reasonably infer that the real-world problems and urban planning technology influenced students' academic success.

Affective Domain

Interest linked to self-efficacy. As observed in Chapter 5, some students linked their interest in mathematics to beliefs about their mathematical ability. Initially, students believed that mathematics was a boring subject and had a very moderate belief in their own ability. However, by the end of the urban planning project, students’ beliefs changed. For example, students’ beliefs were context-based, depending on what activity and mathematics they were performing. If they believed that the work would be helpful to others, then they were more likely to be interested in the work, and as a result, they were more successful in their mathematics performance. This supports findings from Pintrich et al. (2002), who stated that self-efficacy predicts initial engagement and task performance; in turn, success leads to greater intrinsic
interest and a greater likelihood of engaging in that task in the future, often at a more challenging level.

**Failure in mathematics became a self-fulfilling prophecy.** Examination of another case that permeated several of the students’ experiences suggested that some students believed that they were not good at mathematics and they never would be. However, as they progressed with their urban planning experiences and began to develop understandings of the mathematics they were learning, their belief shifted to a more positive view that they were good at mathematics when they participated in SSJY. Thus, they held the belief that under certain circumstances, they could be successful in mathematics. When they were interested in learning about urban planning in their own neighborhoods, they had less anxiety and doubt about their mathematical ability. This finding reinforced the belief that performance and motivation are in part determined by how effective people believe they can be. As a result people behave in the way that executes their initial beliefs; thus, self-efficacy functions as a self-fulfilling prophecy (Bandura, 1986; Tait–McCutcheon, 2008).

**Change in beliefs about ‘what is mathematics.’** Research also indicates that when students start to broaden their definitions of what it means to do mathematics, they can learn that in certain contexts their ability in mathematics is better than what they initially believed (House, 1993). Several cases confirmed that this shift was possible. Initially students felt that they were generally uncomfortable with their mathematical ability; however, as they began to understand that the work in SSJY was mathematics, their belief in their own ability improved.
Cognitive Domain

In terms of cognitive domain, two themes permeated the students’ interviews. Students’ increased belief in their mathematical ability was linked to understanding the context of the graphs as well as their comfort with the material.

**The importance of context.** Middleton and Spanias (1999) suggest using real-life problem situations in mathematics instruction to uncover important and interesting knowledge, which can promote understanding. During the urban planning project, students initially had a much lower belief about their mathematical self-efficacy. For example, they understood the idea of temperature from the graphs they were interpreting, but did not understand the context of the graphs; however, by the end of the program, they believed that knowing more about the project allowed them to make more interesting interpretations that would lead to better urban planning decisions. This reinforced students’ belief that mastery experience can increase their own mathematical self-efficacy (Luzzo, et al., 1999).

**With experience comes comfort.** Across the student cases, more experience with the SSJY program led to a notable increase in self-efficacy in interpreting graphs. Initially when students were asked to discuss graphs in front of their classmates, they hesitated; however, by the end of the urban planning project, they showed enthusiasm as they felt more comfortable with the material and felt more confident in being able to interpret and explain the data to their peers. This finding suggests that the continued use of knowledge, such as associating, reasoning, or evaluating over a period of time, can increase the cognitive factor of self-efficacy (Eynde, et al., 2002; Tait–McCutcheon, 2008).
Conative Domain

With regard to conative domain for the students involved in SSJY, the students linked their beliefs about their mathematical ability to the importance of reflecting on the material covered throughout the urban planning project.

The importance of reflection. As stated earlier, when starting SSJY many of the students had low mathematical self-efficacy. They felt that they were unable to interpret graphs and they had no interest in doing so. As they learned more about the importance of graphs to make urban planning decisions and trade-offs, their beliefs in their mathematical ability increased. This finding fortifies the idea that student self-efficacy can be increased through planning and reflection (Dunlap, 2005).

Rules. Transforming students’ self-efficacy is influenced by current social rules and regulations that both support and constrain activity. In this instance, the current policy shifted from traditional mathematics pedagogy to outcomes based pedagogy and the consequent shift from a focus on passive to active students, coupled with SSJY program's commitment to equity and access impacts on the types of technologies (tools) used to act on students' scientific and mathematical concepts. At the micro level, there are rules, such as rules that govern interaction within the student classroom, as indicated by student extracts in Chapter 5.

Community. While the community of the classroom for the urban planning project includes the instructors, students, and myself, we are members of wider communities whose influences we bring to bear on the object.

Division of labor. As the students mostly work in groups, there is both horizontal division of labor among them, with students sharing knowledge and skills and vertical division of labor between them, with brighter students often dominating the group.
Activity Theory and Mathematical Understanding

Survey findings indicated that students involved in the SSJY urban planning project showed a significant increase in their ability to understand graphical interpretations of data from examples of graphing questions obtained from national assessments (Shaughnessy & Zawojewski, 1999; U.S. Department of Education, 2010). Analysis of qualitative data derived from interviews, observations and artifacts of the ten student cases confirmed this finding, as stated in Chapter 5. Although each of the ten students solved their urban planning problems in different ways, three common factors emerged: 1) understanding multiple realizations of the data collected; 2) ability to construct relationships between the data collected, the physical site being studied, the graphs that were created and how they connected to their urban planning decisions; and 3) ability to reflect upon and communicate their understanding of the data.

The Activity System

Object. The object of an activity system is the problem space that the subject acts on and transforms. The object during the urban planning project was twofold: the content of urban planning as well as how to interpret graphs and develop students’ mathematical understanding. This was attempted by linking students’ own mathematical experiences in the urban planning project to the mathematics students were learning at school. Students movement from low to high mathematical understanding of interpreting graphs developed from real-world, contextual-based urban planning problems was captured to make sense of students’ understanding of multiple representations, how they made connections between their sites and the graphs constructed as well as their ability to reflect upon and communicate what was learned from the graphs. Reconstituted in the language of activity theory, the object of this activity, then, is mathematical understanding of graphical interpretations.
Multiple Realizations of Student Collected Data

At the beginning of the urban planning project, few of the students were able to envision ways to apply mathematics to their day-to-day life that did not involve using money. Making connections between what was learned in mathematics class and what students did outside of school was difficult. Similarly, when starting the SSJY program, students could not appropriately interpret graphical data generated from the neighbourhood sites or vacant lots. However, the urban planning project interventions created a shift in how students examined and interpreted graphs. As the program continued, students’ understanding of their own activities evolved: they began to understand that mathematics, graphical data and urban planning are all interconnected.

The ability to understand multiple representations of data is aligned with the new CCSSM, which highlights the importance of using and understanding different but equivalent forms of data to reveal and explain properties within the data (2010). To translate between graphs and tables, one could describe the contents of a table of data in words or interpret a graph at a descriptive level, commenting on the specific structure of the graph. However, interpretation requires rearranging material and sorting important factors. The students used these multiple realizations to interpret the data (Friel, Curcio, & Bright, 2001). Research has shown that if students can grasp the meaning of mathematical concepts by experiencing multiple mathematical representations, they can develop a stronger understanding of the mathematics (Sierpinska, 1994). In this context, the NCTM (2000a) document offers a new process standard that addresses representations. Here, the term representations means the tools used for representing mathematical ideas such as tables, graphs, and equations (Lapp & Cyrus, 2000).
Constructing Relationships

In working with graphs, one could extrapolate or interpolate by noting trends perceived in the data. The knowledge and skills required to locate and use information contained in various formats, including tables and graphs, can improve when students are able to construct relationships between the physical data and the graphs they are interpreting (Lapp & Cyrus, 2000; Shaughnessy & Zawojewski, 1999). Research suggests that students bring to school a considerable amount of knowledge and experience and that students construct meaningful, new ideas by relating them to concepts or activities they have already experienced (Bransford, et al., 2000). The CCSSM (2010) expresses an increased need for students to make these connections between different mathematical topics that they are learning. The CCSSM also calls for an increase in use of technological tools in mathematics classrooms. When making mathematical models of real world problems, the document puts forward the idea that technologies can enable students to visualize the results of varying assumptions, explore consequences, and compare predictions with data. Mathematically proficient students at various grade levels are able to identify relevant external mathematical resources, such as digital content located on a website, and use them to pose or solve problems. They have the ability to use technological tools to explore and deepen their understanding of concepts.

During the urban planning process, many of the students observed and interviewed were confused about how the graphs related to the physical site they were studying. However, over time the students were able to take the data collected, create graphs and analyze the data in order to make decisions about the optimal redesign of the site. This aligns with the CCSSM (2010) focus on Modeling where students will be able to make connections from classroom mathematics and statistics to everyday life and decision-making. The SSJY students used modeling to choose
appropriate mathematics such as interpreting graphs to analyze empirical situations, to understand them better, and to improve urban planning decisions (Council of Chief State School Officers, 2010). The SSJY students also showed mathematical proficiency by identifying relevant external mathematical resources, such as CommunityViz and Microsoft Excel, to solve their urban planning problems. They were able to use technological tools to explore and deepen their understanding of urban planning concepts (Council of Chief State School Officers, 2010). This aligns with Roth and Barton (2004), who emphasize that researchers, teacher educators, and policy makers should set aside a deficit perspective on teachers and students and instead connect formal curricula to funds of knowledge that are developed in fields away from classrooms. It becomes important to examine mathematics education in relation to social justice and identify hegemonies that create and maintain success and failure along the socio-economic borders that separate urban students from their more affluent counterparts.

**Reflection and Communication**

Reflection and communication are important aspects of mathematical comprehension (Hiebert, et al., 1997). Communicating mathematical concepts involves inference, application, synthesis, and evaluation. In comprehending text, readers need to be able to ask questions that help them identify gaps, contradictions, incongruities, anomalies, and ambiguities in their knowledge bases and in the text itself (Friel, et al., 2001). Thus, if students are to communicate mathematically and use mathematics in a productive way, they must find meaningful understandings for the symbols and notation associated with the language of mathematics. According to the CCSSM (2010), students with mathematical understanding are able to state assumptions, definitions, and previously established results in constructing arguments. They justify their conclusions, communicate them to others, and respond to the arguments of others.
As the urban planning project progressed, many of the students were able to analyze the data collected and reason inductively about the data, making plausible urban planning arguments that took into account the contexts from which the data emerged. From these arguments, students created presentations and discussed their urban plans on several occasions. Many students started the program believing that money was the only reason for using mathematics in their day-to-day lives. However, over the course of the urban planning project, students became interested in the project, felt comfortable with the concepts and were eager to talk to others about their urban planning decisions. Students believed that being able to use technologically created graphs to make decisions assisted with their ability to communicate their thoughts about what should be done with the vacant lot. Subsequently, this finding reveals that the act of communication contributes strongly to connecting intuitive ideas about mathematics to the abstract symbols and notation that constitute the language of mathematics. Communicating the data to others brings meaning to the mathematics students learn (Hiebert & Carpenter, 1992).

**Rules.** Prior to this study, students that were involved with SSJY, Urban Planning Project struggled with making urban planning decisions and would generally add buildings and features to their redesigns that were interesting as opposed to making decisions that were based on the research that was done. However, using visually interesting graphs from the CommunityViz software influenced the decisions made during the urban planning process. However, another rule driving the use of these technological tools was the CCSSM national policies that discuss the importance of students using tools to help with mathematical problem solving and modeling (Council of Chief State School Officers, 2010). Another rule driving the urban planning project was using activities that were meaningful to the students to increase their interest in the problems that the students were to solve.
Subject position and tools. The decision to use CommunityViz as part of the urban planning project was motivated by the belief that professional technologies can be used as tools to develop students’ conceptual understanding of interpretation of graphical data (Beckett & Shaffer, 2005; Shaffer, 2004). There is also awareness of growing demand in the workplace for technological literacy and that teachers (all my students are teachers) need to be able to use more progressive technologies in their own classrooms. The decision to have students learn about graphs through solving urban planning projects in their own neighborhoods was motivated by research indicating the importance of students working through mathematical problems that have meaningful contexts for them (Beckett & Shaffer, 2005; Lapp & Cyrus, 2000).

Community. While the community of the classroom for the urban planning project includes the instructors, students, and myself, we were members of wider communities whose influences we bring to bear on the object.

Division of labor. Research has shown that the use of computers and cooperative learning methods affects the roles of students (Chinnappan & Thomas, 2000; Mokros & Tinker, 1987). As the teacher becomes more of a facilitator and students direct their own pace and sequencing; that is, the introduction of the CommunityViz software forces a shift from a teacher centered to a student centered approach which allows for more instances of student motivated mathematical experiences. The division of labor has shifted, with students taking a more active role in setting the pace of their engagement.

Conclusions and Implications

This study viewed the potential process of learning mathematics (specifically interpreting graphs) in interesting and meaningful ways for urban students and how that context influenced students’ self-efficacy and mathematical understanding. Three important domains shaped self-
efficacy in mathematics for the students: the affective, cognitive and conative beliefs that students had about their own mathematical ability. Mathematical understanding was shaped by the ways students made connections between the different representations of data collected, the way they connected these representations to real-world problems, and the way they reflected upon and communicated their understanding of representations to others. Thus, the conclusions and implications of this study are based on findings from the survey and case study analysis. Implications were made about informal and formal learning, classroom teaching and the use of professional technologies in classroom mathematics.

**Informal Learning**

Nationwide, many after-school programs have focused on getting students excited about STEM learning. Afterschool programs during the school year allow students to further their science knowledge in a setting where they can experience collaborative and creative processes that have relevance to real-world problems. Schools play an obvious and critical role in promoting learning, but we know that children and youth spend the majority of their time outside of school (Larson & Verma, 1999). The afterschool urban planning project allowed for hands-on, project-based activities that build upon and reinforce concepts learned in school without feeling like more school time. Students in the SSJY informal education program showed success in applying mathematics and science skills learned to urban planning decisions with the help of professional urban planning technologies. Several of the students attributed their success to the summer program. Although many after school programs exist throughout the school year, findings may also suggest that involving an intensive summer program can positively impact students’ immersion into difficult mathematical tasks. This finding builds upon research that
indicates that for urban students, summer represents an opportunity for experiences that enrich and complement the school year and promote continuous learning and development.

What separates this program from many other STEM-based informal programs is the importance of having a social justice focus. Students involved in SSJY are not only learning important STEM-related skills, but are also using these skills to promote change within their own neighborhoods. Not only were these students trying to improve a neighborhood by redesigning aging and vacant lots, they were also trying to make a positive change in their own environment. The focus of this program was to promote deeper understandings of mathematical concepts by engaging students in solving problems in their own neighborhoods by using professional technologies. These findings suggest that when students solve problems that are meaningful to them, they gain both mathematical competence and increase self-efficacy. This project is in line with the CCSSM emphasis on linking “… classroom mathematics and statistics to everyday life, work, and decision-making…. to analyze empirical situations, to understand them better, and to improve decisions” (p. 72)

**Implication for classroom teachers**

The impetus of this study was to explore how presenting real-world problems can influence students’ mathematical understanding of graphical interpretations. Students involved in the SSJY urban planning project showed improvement in mathematical self-efficacy and understanding while involved in real-world, urban planning projects. This success implies that classroom teachers should create more meaningful, real-world problems for students to solve. This is aligned with students solving real-world mathematics exercises with meaningful connections with reasoning and sense-making and mathematical modeling (NCTM, 2000a). According to the CCSSM, there needs to be a focus on creating real-life mathematical situations
by “choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions.” (Council of Chief State School Officers, 2010, p. 72). Mathematics curricula must show students the power of reasoning and sense making as they explore real world mathematical structures (NCTM, 2000a).

This study also indicates the importance of giving students more access to professional technologies as they engage in real-world mathematical tasks. Findings indicated that students found CommunityViz urban planning software useful for making their urban planning decisions. The graphs created by CommunityViz allowed students to interpret data and make decisions and thus increased student engagement in the urban planning process. Using technological tools aligns with the CCSSM goal of teachers using appropriate tools to help students solve mathematical problems. When students have access to appropriate technology, they have the tools to explore a topic in a meaningful way and achieve the deep understanding that is required in the Common Core State Standards for Mathematics (2010).

**Professional Technologies in the classroom**

GIS technologies provide an excellent way to learn mathematical concepts and skills. The CCSSM (Council of Chief State School Officers, 2010) and the NCTM Standards (NCTM, 2000a) affirm the value of visualizing numbers: representing numbers, understanding patterns, relationships, and function, 2-D and 3-D geometric and spatial relationships, probability, statistics, change, models, measurements, problem solving, reasoning, connections, and communications. Every one of these standards can be explored using GIS tools and methods. NCTM’s curricular “focal points” also connect well with GIS (NCTM, 2009). A focal point must pass three rigorous tests: Is it mathematically important in and outside of school? Does it “fit” with what is known about learning mathematics? Does it connect logically with the mathematics
in earlier and later grade levels? When we connect latitude and longitude to the Cartesian coordinate system, when we measure area, shape, size, and distance in different map projections, when we compare geometric to exponential growth rates of agricultural output, even when we explain the Earth’s shape, rotation, and revolution, we are applying geographic and mathematical concepts that GIS can help students understand.

**Limitations of the Study**

The goal of this study was to implement a comprehensive two-year study of the SSJY students using a longitudinal and mixed-method design. However, there were several limitations to this design. One limitation of the study was the small sample size for the survey, which does not account for a wider range of accuracy. Although the case study of ten students’ experiences has implications for high school students in similar urban settings, findings from these cases cannot be generalized to all high school students. Although the cases proved to be a rich description of the ten participants’ experiences in SSJY, findings are certainly not definitive.

Based on the reliability tests, the instrument also had room for improvement, as surveys do not fully capture the variables of interest due to self-reporting and restricted Likert-scales. Thus, it is important to keep these issues in mind when thinking about their generalizability as well.

More research is needed in the fields of real-world mathematics problems and student self-efficacy in mathematics education. The next section expands upon some of these ideas for future research.

**Recommendations for Future Research**

The study included some additional limitations, which were not addressed in the previous section. This omission was intentional because some of the shortcomings of this study provide
useful directions for future research into the question of effective learning environments for traditionally underserved students. The sample size was relatively small for the quantitative data, and the research design would have been more robust if applied on a larger scale. Also, the student survey could be redesigned to target a larger population of high school students.

As this was a descriptive study, it would be worthwhile to explore future research where the surveys were administered to a control group in an effort to explore the differences between students that received the intervention and those who did not. Even within the SSJY program, not every student was involved in the urban planning project; these students are a possible control group who could be presented with such a survey. It would be interesting to capture the differences in mathematical self-efficacy and understanding between students that were involved in urban planning and those who were not.

Secondly, the focus of this research project was to explore the students’ learning environment. The only voices offering perspectives on the nature of the effective learning environment in the current study were those of the students. In an effort to create a more holistic picture of the nature of the urban planning project, collecting data from the curriculum specialists as well as the teachers would give a broader view of the program.

Tracking student progress beyond the two year urban planning project would offer a more holistic perspective on the influence of SSJY on mathematical understanding and self-efficacy. Starting a similar research agenda with an afterschool program over the full four years of high school could accomplish this goal.

A third avenue for further research involves exploring the use of GIS in mathematics classrooms. Due to their cost and complexity, GIS technologies like CommunityViz are not currently used in classrooms. Consequently, future research could explore new technologies that
might provide a starting point for students in classrooms which could ultimately develop meaningful connections between mathematics and urban planning. In order to scale the use and implementation of GIS-based urban planning opportunities for youth, new user-friendly, easily implemented GIS technologies must be implemented in traditional K-12 settings. It will also be important to use GIS to explore other mathematical concepts more deeply than is possible that other educational technologies. In this study, the GIS technology allowed students to bypass the mathematics used to create these graphs in order to apply the data to real-world problems. However, these “black-boxed” algorithms also represent a learning opportunity for students to explore that additional research could explore.

For current GIS software products to support the teaching and learning of spatial thinking in the K–12 context, they must have the capacity to (1) provide spatial data structures as well as coding systems for non-spatial data, (2) offer multiple representations of working and final results, and (3) perform functions that manipulate the structural relations of data sets. Future research into the advent of GIS and computer displays of geographic data will assist with aligning the eight standards of mathematical practice outlined in the CCSSM (2010). The spatial nature of GIS will allow students the opportunity to solve mathematics tasks that will cut across many of these standards. Using GIS to explore local urban planning problems gives students the opportunity to make sense of problems and persevere in solving them by using appropriate tools to help visualize and make sense of data. The graphs that are created through the urban planning technology were used to construct viable arguments and make effective urban planning decisions (Council of Chief State School Officers, 2010). Future research into the benefits of GIS in the classroom will explore ways of motivating teachers and students to work simultaneously across
the mathematical strands as well as across science, technology, engineering and mathematics curricula.

**Closing Comments**

The first chapter started with the following quote from John Dewey: “Give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking; learning naturally results.” I feel that this time-honored and common sense belief has been left behind in modern education – that people learn most when they are actively involved in their learning and find the material relevant and attractive in some way. There needs to be more of an emphasis on learners feeling a sense of control over learning situations and on providing opportunities to reflect on the learning experiences so they relate, connect and transfer to real life. The long and sometime arduous task of doing this dissertation has reinforced the importance of students learning mathematics and proper use of professional technologies within the STEM framework. STEM education creates critical thinkers; increases STEM related literacy, and enable the next generation of innovators. Innovation leads to new products and processes that sustain our economies, all of which involves a solid knowledge base in the STEM areas. Upon reflection on the SSJY urban planning project, this research and my own personal experiences, I truly believe that a national and international focus on creating STEM education programs that inspire an internal motivation to explore STEM related school and careers will only lead to a more exciting future for everyone.
References


Appendix A

Student Survey

Part I: Understanding of Graphs
Directions: We want to know what you understand about graphs. Please answer the following questions as well as you can. For each question, circle the number under the answer that you believe to be the correct answer. If you have difficulty in understanding any question, ask the proctor for help.

1. Jim made the graph above. Which of these could be the title for the graph?
   a. Number of students who walked to school on Monday through Friday
   b. Number of dogs in five states
   c. Number of bottles collected by three students
   d. Number of students in each of ten clubs

2. Which of the following graphs best illustrates the relationship between exercise time and total calories burned for an individual?
   a. 
   b. 
   c. 
   d.
3. The total distances covered by two runners during the first 28 minutes of a race are shown in the graph above. How long after the start of the race did one runner pass the other?

   a. 3 minutes
   b. 8 minutes
   c. 12 minutes
   d. 14 minutes
   e. 28 minutes

4. In the graph above, each dot shows the number of sit-ups and the corresponding age for one of 13 people. According to this graph, what is the median number of sit-ups for these 13 people?

   a. 15
   b. 20
   c. 45
   d. 50
   e. 55
5. How much will 18 pounds of peanuts cost?
   a. $31.50  
   b. $34.00  
   c. $36.00  
   d. $40.50  
   e. $45.00

6. For a science project, Marsha made the scatterplot above that gives the test scores for the students in her math class and the corresponding average number of fish meals per month. According to the scatterplot, what is the relationship between test scores and the average number of fish meals per month?
   a. There appears to be no relationship.  
   b. Students who eat fish more often score higher on tests.  
   c. Students who eat fish more often score lower on tests.  
   d. Students who eat fish 4-6 times per month score higher on tests than those who do not eat fish that often.  
   e. Students who eat fish 7 times per month score lower on tests than those who do not eat fish that often.

<table>
<thead>
<tr>
<th>Total Number of Pounds Purchased</th>
<th>Cost of Peanuts Per Pound</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>$2.50</td>
</tr>
<tr>
<td>6–10</td>
<td>$2.25</td>
</tr>
<tr>
<td>11–20</td>
<td>$2.00</td>
</tr>
<tr>
<td>Over 20</td>
<td>$1.75</td>
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</table>
Part II: Self-Efficacy in interpreting graphs
Directions: We want to know what you think about mathematics and interpreting graphs. Please answer the following questions as well as you can. There are no right answers, so please tell us what you really think. For each question, circle the number under the answer that best describes what you think or feel. Circle 1 to 2 if you are not very confident, 3 to 8 if you are moderately confident and 9 to 10 if you are very confident. If you have difficulty in understanding any question, ask the proctor for help.

Suppose that you were asked the following math question. Please indicate how confident you are that you would give the correct answer to each question. Please do not attempt to solve the problem given.

Tom went to the grocery store. The graph below shows Tom's distance from home during his trip.

![Graph of Tom's trip to the grocery store](image)

Tom stopped twice to rest on his trip to the store. What is the total amount of time that he spent resting?

1. If I did well on a question like this, it was because it was easy.
   
<table>
<thead>
<tr>
<th>Not at all confident</th>
<th>Moderately Confident</th>
<th>Totally Confident</th>
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<tr>
<td>1  2  3</td>
<td>4  5  6</td>
<td>7  8  9  10</td>
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</tbody>
</table>

2. If I do well on a question like this, it was because I worked hard.

<table>
<thead>
<tr>
<th>Not at all confident</th>
<th>Moderately Confident</th>
<th>Totally Confident</th>
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<tr>
<td>1  2  3</td>
<td>4  5  6</td>
<td>7  8  9  10</td>
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</table>
3. If I do poorly on a question like this, it was because my memory let me down.

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<thead>
<tr>
<th>Not at all confident</th>
<th>Moderately Confident</th>
<th>Totally Confident</th>
</tr>
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<td>2</td>
<td>3</td>
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<tr>
<td>4</td>
<td>5</td>
<td>6</td>
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<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Graphs do not make sense to me.

<table>
<thead>
<tr>
<th>Not at all confident</th>
<th>Moderately Confident</th>
<th>Totally Confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
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<td>9</td>
</tr>
<tr>
<td>10</td>
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<td></td>
</tr>
</tbody>
</table>

5. I like solving questions like this, it is like solving a puzzle.

<table>
<thead>
<tr>
<th>Not at all confident</th>
<th>Moderately Confident</th>
<th>Totally Confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
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<td>9</td>
</tr>
<tr>
<td>10</td>
<td></td>
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</tbody>
</table>

Part III: Please answer the following questions to the best of your ability

6. This question requires you to show your work and explain your reasoning. You may use drawings, words, and numbers in your explanation. Your answer should be clear enough so that another person could read it and understand your thinking. It is important that you show all of your work.

<table>
<thead>
<tr>
<th>Month</th>
<th>Daily Ridership</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>14000</td>
</tr>
<tr>
<td>November</td>
<td>14100</td>
</tr>
<tr>
<td>December</td>
<td>14100</td>
</tr>
<tr>
<td>January</td>
<td>14200</td>
</tr>
<tr>
<td>February</td>
<td>14300</td>
</tr>
<tr>
<td>March</td>
<td>14600</td>
</tr>
</tbody>
</table>

The data in the table above has been correctly represented by both graphs shown below.
a. Which graph would be best to help convince others that the Metro Rail Company made a lot more money from ticket sales in March than in October?

b. Explain your reason for making this selection.

c. Why might people who thought that there was little difference between October and March ticket sales consider the graph you chose to be misleading?

2.

The above graph was created by students that were studying noise pollution levels at a park in Dorchester. Twenty data points were collected and the noise pollution was measured in decibels. Please answer the following questions

1. What does this graph show?

2. Why do we want to be creating these graphs?
a. What will we do with them?

3. What are three observations that you notice about the data (above)? Why did you choose these three details?

   a. Why those three things?

Part IV: Math Confidence

1. I am good at mathematics.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

2. Mathematics is easier to do if I can look at a graph

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

3. Graphs are useful in many different classes.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
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4. Mathematics is not necessary in everyday living.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
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</table>

5. I use mathematics when I am at SSJY.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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</table>

6. I feel confident in my ability to express what is written on a graph.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
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7. It is important to use graphical representations to explain what I learn.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
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</table>

8. I am not so good at mathematics.

   Strongly Disagree  Disagree  Agree  Strongly Agree
   1                   2           3     4

9. Graphs can help with presenting difficult mathematical ideas.

   Strongly Disagree  Disagree  Agree  Strongly Agree
   1                   2           3     4

Directions: We want to know what you think about using Excel and CommunityViz technology. Please answer the following questions as well as you can. There are no right answers, so please tell us what you really think. For each question, circle the number under the answer that best describes what you think or feel. Circle 1 to 2 if you are not very confident, 3 to 8 if you are moderately confident and 9 to 10 if you are very confident. If you have difficulty in understanding any question, ask the proctor for help.

I could complete the job using CommunityViz/Excel …

…if there was someone given me step-by-step instructions.

   Not at all confident  Moderately Confident  Totally Confident
   1                   2           3     4     5     6     7     8     9     10

…if there was no one around to tell me what to do as I go.

   Not at all confident  Moderately Confident  Totally Confident
   1                   2           3     4     5     6     7     8     9     10

…I had never used software like it before.

   Not at all confident  Moderately Confident  Totally Confident
   1                   2           3     4     5     6     7     8     9     10

…I had seen someone else using it before trying myself.

   Not at all confident  Moderately Confident  Totally Confident
   1                   2           3     4     5     6     7     8     9     10
…if I had only a guided manual to help me through the project.

<table>
<thead>
<tr>
<th>Not at all confident</th>
<th>Moderately Confident</th>
<th>Totally Confident</th>
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I could complete the job using CommunityViz/Excel …

…if I had seen someone for help if I got stuck.

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…if someone else had helped me get started.

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…if I had a lot of time to complete the job for which the software was provided.

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…if I had just the computer help for assistance.

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…if someone showed me how to do it first.

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…if I had used similar software before this one to do the same job.

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Appendix B

Interview Protocol

Part 1: Mathematics experiences and self-efficacy

I am going to ask you several questions about a specific subject you study in school. I want you to think about the math classes you have taken as well as other experiences you have had involving math.

1. What do you do to help yourself learn math?
2. How would you rate your ability in math on a scale of 1 (lowest) to 10 (highest)? Why?
3. What do you like to do that is related to math outside of school?
4. Tell me about a time you experienced a setback in math. How did you deal with it?
5. Tell me a story that explains the type of student you are in math. In other words, share something that has happened to you that involves this subject and perhaps your parents, teachers, or friends.

Part 2:

The above graph is a surface chart that shows data collected at a park similar to the parks that you have been working with during the summer institute.
Please answer the following questions:

1. What does this graph show?
2. Why would someone create these types of graphs?
3. Take two minutes to examine the graph. When you have finished, please share three observations that you notice when you look at this graph? Why those three details?
4. How comfortable are you now at interpreting the information from a graph like this?
5. When presenting this graph to other people, what would be most important to discuss? What part of this graph may be confusing to someone new to our project? How would you help them understand?
Appendix C

Artifacts

Graph Type: _________________________
⇒ Insert graph here

1. Please list all variables used to develop the graph (above). Do you see any relationship between these variables? If yes, please explain.

2. How does this graph relate to the data that you collected?

3. What are three observations that you notice about the data (above)? Why did you choose these three details?

4. What information from this graph would be important for your presentation? Why?

5. What might be confusing about this graph for other people? How can you help them understand the graph?

6. If you could add anything to this graph, what would it be?

7. Where is the highest point on the graph, why might it be the highest? Where is the lowest point, why might it be the lowest?
Appendix D

Visiting the Site – Excel Data

<<Insert the Excel graphs here>>

When visiting the site we tested for ….

The graph above tells me about …

The variables involved in this graph are…

Three major observations I noticed from this graph are:
1).
2).
3).

These observations tell me what about what we can build on the site?
1).
2).
3).

Urban Plan #1

<<Insert a snapshot of the site here>>

<<Insert graph 1 of the site here>>   <<Insert graph 2 of the site here>>   <<Insert graph 3 of the site here>>

Describe the site here
Please describe what the important parts of the site are to you here. Mention if you think this site have a Commercial, Residential or Mixed focus. What reason do you have for this decision?

Three important things about this site are:
1).
2).
3).

Why do you think these things are important?
When you look at the graphs above, what are three things that you notice that make this a good site
1).
2).
3).
When you look at the graphs above, what are three things that you notice that you would like to change about your site?
1).
2).
3).

Urban Plan #2

<<Insert a snapshot of the site here>>

<<Insert graph 1 of the site here>>  <<Insert graph 2 of the site here>>  <<Insert graph 3 of the site here>>

Describe the site here
Please describe what the important parts of the site are to you here. Mention if you think this site have a Commercial, Residential or Mixed focus. What reason do you have for this decision?

Three important things about this site are:
1).
2).
3).
Why do you think these things are important?

When you look at the graphs above, what are three things that you notice that make this a good site
1).
2).
3).
When you look at the graphs above, what are three things that you notice that you would like to change about your site?
1).
2).
3).
Urban Plan #3 – Changing Assumptions

<<Insert a snapshot of the site here>>

<<Insert graph 1 of the site here>> | <<Insert graph 2 of the site here>> | <<Insert graph 3 of the site here>>

The assumptions that I changed from site 2 are:
1).
2).
3).

Three important things about this site are:
1).
2).
3).

Why do you think these things are important?

When you look at the graphs above, what are three things that you notice that make this a good site
1).
2).
3).

When you look at the graphs above, what are three things that you notice that you would like to change about your site?
1).
2).
3).

What graphs changed from Site 2 to Site 3 when you changed the assumptions. What did that do to change your thoughts about Site 3?

Recommendations

From your 3 sites, which scenario would you recommend to be accepted? Describe the scenario

Give 3 pieces of evidence why you would recommend that site
1)
2)
3)
How did tweaking the assumptions improve or make your scenario worse?

Each person please write a paragraph about why this process is important to them. What did you learn from this project?