Effects of an inquiry-based curricular program on aspects of critical thinking skills and dispositions

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Abstract

The purpose of this study was to determine whether student participation in an inquiry-based curricular treatment contributes to pre-post test differences in disposition toward critical thinking and critical thinking skills. To achieve this purpose, non-experimental pre-post test research design was utilized. The sample population for this study included 64 high school freshmen enrolled in a mathematics and science magnet program in a large suburban mid-Atlantic school district.

The unit of analysis for this study was the class of students. The school conducted pre- and post-testing with this class of students using the California Critical Thinking Skills Test and the California Critical Thinking Dispositions Inventory during the 2014-15 academic year. The researcher sought and received permission to access archival data for the class serving as the sample in this study.

Paired t-tests used to answer the research questions and to address the study purpose demonstrated no significant gains in critical thinking skills and dispositions. Additional analysis using repeated measures MANOVA for two specific sets of critical thinking skills and dispositions revealed increased post-test scores in analysis and inquisitiveness as the result of the curricular intervention, and increased post-test scores in interpretation and open-mindedness as a result of the curricular intervention.

A number of implications for practice and future research were discussed, including a recommendation for a longitudinal study utilizing the sample population for this study. Additional recommendations for practice included action research studies to inform teachers of the outcomes of curricular interventions designed to develop students' critical thinking skills and dispositions, and additional teacher professional development focused on curricular alignment with critical thinking skills and dispositions and assessments which measure their change.

Recommendations for future research are focused at the K-12 level as there is limited research at this level. This research should address consideration of critical thinking skills and dispositions in the development of curriculum and pedagogy, assessment of critical thinking skills and dispositions independently and as part of a curriculum, and longitudinal studies to examine student growth between entry and exit points in K-12 education.

Dedication

My parents were my first teachers. With their love and support, Maryellen and James Caflin placed countless opportunities in front of me, and showed me how to open the doors.

Each of us can trace in our own professional development the hands of our mentors. Sister Marian William Hoban, IHM, Ph.D., taught me to think, to write and to lead. Dr. Lewis B. Morgan, Ph. D., taught me how to grow and improve in my relationships with students, families, and colleagues. Their heartfelt words and unwavering ethics have remained with me and guided every effort.

My husband and I have now spent about 15 of our 39 years of marriage knee-deep in the delight, despair, and utter tedium that describes life in two doctoral programs. Don't for a minute think that your sacrifices have gone unnoticed or unappreciated during the past seven years, Pete. Now it's time for us.

My children Meaghan and Peter - you are my legacy –I have watched you grow to be amazing, interesting, strong adults.   Every journey with you has been memorable, but your support and encouragement on this one has been priceless.

And finally, for my grandchildren Cole and James and those who may follow: you did not begin this journey with me, but you have inspired me to complete it so that I can have more time to spend with each of you.

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Dr. David Feldon served as a committee member prior to assuming a position at a Utah State University. Through our discussions I was able to grasp the role of metacognitive knowledge and processes in the ongoing success of inquiry pedagogy, applying that to both students and teachers. Thank you for preparing me to develop a study in which the curricular intervention itself was the topic of research

Finally, in the fall of 2012 Casey Robinson, Liz Beatty and I found ourselves together preparing to begin our dissertation work. For the past three years these amazing women have been my cohort as we gathered regularly through this process. Your support, encouragement, and fortune cookie advice has sustained me through the challenges of analyzing, writing, formatting, and completing this dissertation. We did it!

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CHAPTER ONE

INTRODUCTION

A critical issue for contemporary educators is the preparation of students for the challenges of the 21st century. Worldwide economic changes and ecological concerns, technological advancements, and the "flattening" of the world have impacted the skills and knowledge requisite for productive and responsible citizens. A number of research and advocacy organizations, including the Mid-Continent Research for Education and the Learning (Marzano, 1998) and the Partnership for 21st Century Skills (2006b) agree that the requirements for 21st century education include creativity and innovation skills, information and communications technology (ICT) skills, global/cultural awareness, critical thinking and problem solving skills, and communication and collaboration skills.

21st century skills "equip students with the competencies necessary to reason about social affairs in a rapidly changing world" (Ku, 2009, p.70). Renzulli, Reis and Thompson (2009) recommend curricula and instruction that incorporate dynamic approaches to teaching critical thinking. Curriculum and instruction must be tailored to developing 21st century skills so that students can meet the demand for employees who, when faced with the constant immersion of ideas and information, can solve complex problems in productive collaborations with others (Skiba, Tan, Sternberg & Grigorenko, 2010).

The integration of 21st century skills into the curriculum should provide the opportunity for students to gain deep content knowledge while developing the ability to apply this knowledge within and across disciplines (Daud & Husin, 2004; Silva, 2000; Sternberg, 2009), thus supporting the expectation that building critical thinking skills in science and mathematics, for example, should transfer within these disciplines as well as to increased skills in language arts. Educators must also be aware that the constantly changing world students inhabit is an information culture saturated with ongoing technological advances (Richards, 2010) which demands the integration of technology and learning experiences necessary for promoting 21st century competencies (Bonk & Smith, 1998; Dixon, Cassidy, Cross & Williams, 2005).

Among the aforementioned skills, critical thinking has long been tied to the history of American education. Critical thinking can be defined as "the process of purposeful, self-regulatory judgment" that "gives reasoned consideration to evidence, context, conceptualizations, methods and criteria" (Facione, 1990c). Once thought to be the domain of only high-ability students (Cornell, 1984, Passow, 1955), these "gifted" students were the first and only students to receive formal instruction in critical thinking skills (Hubin, 1998; Karnes and Nugent, 2002; Van Tassel-Baska, 2003). The enactment of the United States Department of Education's No Child Left Behind Act (NCLB) (2002) set as law the expectation that all students would demonstrate proficiency in critical thinking skills. This legislation, combined with additional research advocating the importance of critical thinking skills for all students (Bloom, 1956; Eisner, 2000; Fuerstein, Rand, Hoffman and Miller, 1980) presented a compelling need to expose all students to critical thinking skills.

Science inquiry, as a pedagogical approach, presents a tool for the infusion of critical thinking skills and dispositions into content areas. Lawson (1993) concluded that the teaching of critical thinking is effective at all grade levels, focusing on the importance of giving students the opportunity to "explore, raise questions, generate, and test several possible answers." He further discusses the role that inquiry plays in the development of the thinking patterns that enable students to use critical thinking skills, and summarizes by commenting that all teachers need to be committed "to teach in such a way that the key thinking skills of the free mind are 'exercised' and improved so that students learn 'how to learn' and not simply 'what to learn'" (p. 177).

Curricular and instructional recommendations of the National Council of Teachers of Mathematics (NCTM) (1989, 1991, and 2000) have led the way in a broad-based reform movement focused on teaching and learning within mathematics classrooms through the use of inquiry-based learning. During the past twenty-five years mathematics pedagogy has been shifting from traditional classrooms that focus on students' acquiring proficiency in reproducing existing solution methods to class-rooms that support instructional goals of helping students construct personally meaningful conceptions of mathematical topics (Fraivillig, Murphy & Furson, 1999). Evidence from secondary school mathematics programs lend support to the effectiveness of instructional approaches including inquiry, which are student-centered (Boaler, 1998; Clarke, Breed & Fraser, 2004: Slavin, Lake & Groff, 2009).

Research also suggests that students are able to solve mathematical problems, including word problems, without direct instruction on how to do so (Warfield, 2011). Mokros et al. (1995) observed that students have to do mathematics for themselves rather than only learning through the example of others and rote repetition. This is in keeping with constructivism, which provides a philosophical underpinning for methods frequently used in reform-based instruction. For example, inquiry-based instruction is supported by instructional methods that encourage students to express their own ideas about mathematics or science through the creation of solutions and having opportunities to share, extend, defend and revise them (Bransford, Brown & Cocking, 2000).

NCLB contained four basic education reform principles: stronger accountability for results, increased flexibility and local control, expanded options for parents, and an emphasis on teaching methods that have been proven to work. NCLB required each state to establish state academic standards and a state testing system that met federal requirements with accountability measured in the form of Adequate Yearly Progress (AYP). This legislation aims to improve reading, math, writing, and science competencies. What is not measured, however, are critical thinking skills which are crucial to success in the 21st century (Conley, 2007; Silva, 2008; Zhao, 2007).

Indeed, critics of NCLB have testified before Congress that NCLB measurements foster rote memorization rather than the type of thinking skills that are required in the 21st century, and that the assessments are not in line with 21st century thinking (Hardy, 2007).

The Partnership for 21^{st} Century Skills has developed a plan for a unified, collective vision for 21^{st} century learning that includes core subjects, 21st century content, and specific life and learning skills including critical thinking learning (Hardy, 2007, p. 20). This movement places less emphasis on the teaching and testing isolated content which developed as a response to NCLB legislation, and instead seeks to restructure the learning experiences in the classroom to include activities such as collaborative interdisciplinary problem solving (Huber & Breen, 2007; Newman & Wehlage, 1995) which forms the basis for critical thinking. Brown (2006) suggests that this learning environment resembles Dewey's (1938) idea of productive inquiry, where student collaboration results in learning from trial and error and discussion and promotes critical thinking.

Schoen and Fusarelli (2008) point out that "21st century skills proponents advocate a focus on the contexts for learning, and NCLB proponents emphasize the content of learning through standards-based teaching and testing" (p. 183). Suarez-Orozco and Gardner pose the question of how should to envision an education for the new millennium:

> More than any generation before them, today's children need to develop cognitive skills that allow them to work comfortably with the new and evolving technologies. They need to be able to sift through unprecedented amounts of information to figure out what is true, what is trivial, what is worth retaining, and how to synthesize disparate bits into a meaningful whole. They need to learn how to approach issues and problems that cannot be solved within a single discipline, but instead involve a blend of multiple perspectives, (as cited in Marx, 2006, p. 178)

With this in mind, educators are faced with meeting the mandates of NCLB while developing and assessing the skills for the 21^{st} century. NCLB measurements for student success do not incorporate the skill set identified for the 21st century workforce, prompting the Partnership for 21st Century Skills to suggest that:

> Knowledge of core content is necessary, but no longer sufficient, for success in a competitive world. Even if all students mastered core academic subjects, they still would be woefully underprepared to succeed in postsecondary institutions and workplaces, which increasingly value people who can use their knowledge to communicate, collaborate, analyze, create, innovate and problem solve, (2007, p. 3)

A perfect storm of the failure to meet the NCLB goal of 100% proficiency in Math and English Language Arts by 100% of students, the inadequate ranking of the United States compared with other countries on international assessments such as the Programme for International Student Assessment (PISA), and encouragement from the business community to reconsider educational practices has provided the impetus for school leaders to face the challenge of responding simultaneously to calls to increase critical thinking skills and innovation while still meeting the Adequate Yearly Progress (AYP) testing targets of NCLB (Schoen & Fusarelli, 2008, p. 182).

Statement of Problem

Requiring schools to become accountable to the public for student performance has been the impetus behind the No Child Left Behind Act (NCLB), and thus requires individual states to monitor and improve student performance and issue annual publically accessible report cards based on end-of-year test performance for all schools.

The NCLB legislation was a reaction to a twenty year conversation about the diminishing stature of the U.S. education system and the students it produces, who had long been viewed as a sign of national excellence. While the United States had long been able to take justifiable pride in the historical accomplishments of K-12 through post-secondary education and the resulting contributions to the well-being of its citizens, Gardner (1983) warned that the nation was at risk because the once unchallenged U.S. preeminence in industry, science and innovation was being overtaken by competitors from around the world. While many factors could contribute to this shift, Gardner focused on the educational foundations that were being eroded by a rising tide of mediocrity that threatened the future of the nation and its people. International testing data had begun to suggest that other countries were matching and surpassing American educational attainments.

Twenty years later, the Organization for Economic Cooperation and Development (OECD) reported that the United States ranked still as an average performer in reading (14th) and in science (17th), but had dropped below the OECD average in mathematics (25th). Although American students were scoring at a level similar to prior years, other countries were surpassing the United States (Gurria, 2010). Gurria also reported a widening gap between the top ten percent and the bottom ten percent of fifteen year-olds in the United States, a gap similar to that observed between top- and bottom- performing countries participating in the Programme for International Student Assessment (PISA).

During the same year Wagner reported that the U.S. high school graduation rate, which was about 70 percent of the age cohort, lagged well behind countries like

Denmark (96 percent) and Japan (93 percent)—and even Poland (92 percent) and Italy (79 percent) (Wagner, 2010). He further observed that while students were not necessarily receiving a bad education, they were receiving the same education received by students fifty to one hundred years prior. The world around students and its job demands were changing, but the environment inside the classroom has remained unchanged.

Purpose

The purpose of this study was to determine whether student participation in an inquiry-based curricular program contributes to statistically significant differences in pre-post test scores in critical thinking skills and dispositions. To achieve the purpose of this study the following two research questions were posed:

1. Are there statistically significant differences in pre- and post-test scores in critical thinking scores for students participating in an inquiry-based curricular program?
2. Are there statistically significant differences in pre-and post-test scores in critical thinking disposition scores for students participating in an inquiry-based curricular program?

Rationale

School leaders have long been faced with the simultaneous goals of teaching subject-specific content knowledge and interdisciplinary critical thinking skills

(Hatch, 2001; Hill & Larsen, 1992; Westberg & Daoust, 1993; Westberg et al., 2001). The measure of success for tomorrow's students will be their ability to solve complex problems instead of simply memorizing algorithms and definitions (Friedman, 2005: National Academy of Sciences, 2005; National Council of Teachers of Mathematics, 2000). Looking through the lens of the Trends in International Mathematics and Science Study (TIMSS, 2013) and the Programme for International Student Assessment (PISA, 2012) scores, or through the national lens of the National Assessment of Educational Progress (NAEP) (Grigg, Lauko & Brocway, 2006; Lee, Grigg & Dion, 2007) or NCLB scores (USDOE, 2007, 2012), the data indicate that the nation's schools have not been successful in teaching most students to become better critical thinkers or problem solvers. Ten years after NCLB was signed into law, there were calls for change, particularly with reference to artificial goals of proficiency that encourage states to set low standards to make it easier for students to meet the goal (USDOE, 2012).

Students who engage in regular activities designed to promote the development of critical thinking skills performed higher on tasks that required higher order thinking skills (Law and Kaufhold, 2009). Law and Kaufhold's research also supported previous theories about teacher expectations concerning critical thinking skills, finding that when educator self-expectations of ability to promote critical thinking skills were higher, the expectations of student's abilities to use critical thinking skills were also found to be higher (2009).

Tomlinson (2001) addressed the importance of designing lessons for all students that emphasize critical and creative thinking. Tomlinson also emphasized classroom tasks that require students to understand and apply the concepts put forth rather than focus solely on memorization of information.

Research suggests that inquiry learning teaches critical thinking skills; promotes the transfer of concepts to new problem questions; teaches students how to learn and builds self-directed learning skills; and develops student ownership of their inquiry and enhances student interest in the subject matter (Eslinger et al., 2008). Research shows that the amount of student learning that occurs in a classroom is directly proportional to the quality and quantity of student involvement in the educational program (Cooper and Prescott 1989). Yet research studies indicate that teachers typically dominate classroom conversation, consuming nearly 70% of classroom time. Inquiry-based instructional approaches reverse this trend, placing students at the helm of the learning process and teachers in the role of learning facilitator, coach, and modeler. Compared with those in non-inquiry settings, students in inquiry-based classrooms ask more questions, provide better explanations, demonstrate understanding of more content, are more likely to provide supporting evidence for their claims, collaborate more productively and effectively with one another, and are more prone to actively monitor and evaluate their own work (Kolodner et al. 2003; White and Frederiksen 1998).

Peter Facione, who has been one of the leaders in the effort to define and implement assessment measures for critical thinking skills and dispositions, believes “that the heart of education lies in the process of inquiry learning and thinking rather than in the accumulation of disjointed skills and senescent information” (Facione, 1989). The body of his research during the past twenty-five years has been applied to multiple settings including attempts to understand the effect of a curricular intervention – inquiry pedagogy – on the critical thinking and dispositions of students in a wide range of academic programs and levels.

Inquiry pedagogy provides a tool for infusion of critical thinking skills into content areas. At its heart, effective inquiry pedagogy provides students with the opportunity to "explore, raise questions, generate, and test several possible answers (Lawson, 1993). Science inquiry experiences help develop thinking patterns that enable the student to use critical thinking skills, teaching in such a way that students learn not only what to learn but how to learn. Burger and Starbird (2000) urged mathematics instructors to expand instructional practice to include pedagogy which emphasize strategies of critical thinking and analysis which teach students to "solve problems, analyze situations, and sharpen the way they look at the world." Inquiry-based learning in mathematics places the student, the subject and their interaction at the center of the learning experience, transforming the role of the teacher from dispensing knowledge to facilitating learning and significantly increasing the role of the teacher in the thought processes of the student (Academy of Inquiry Based Learning, 2013).

By placing critical thinking and dispositions in the context of integrated science and mathematics courses, the inquiry-based pedagogy can aim to take student learning and thinking to a level wherein the instructor fosters the development of both attitudes and skills that will enable students to gain success in learning. Evidence from secondary-school mathematics lends support to the influence of an inquiry-based learning (IBL) in mathematics (Laursen et al., 2014).

In order to reach greater clarity on these issues and in order to substantiate the impact of critical thinking as an outcome of inquiry pedagogy on the curriculum, there is a need for more research on inquiry pedagogy that aims to promote the development, assessment, and measurement of changes in critical thinking skills (Phillips, Chestnut, and Respond, 2004; Ball & Garton, 2005). By examining the growth of students exposed to a curriculum conducive to the improvement of critical thinking skills, this study will provide data that may suggest the benefit to students from instruction which uses inquiry pedagogy.

Limitations

This study had several limitations.

- This study used a small, non-random sample at one institution.
- There was a heavy reliance on consistent teacher training. Although all of the teachers have participated in similar professional development and ongoing training in inquiry pedagogy, the study did not include any controls for teacher competency, and it was difficult to know whether each teacher implemented the pedagogy in exactly the same way.
- The results of this study cannot be generalized to all populations because only one grade level was studied.
- The study did not control for a number of other variables that may be related to pre- and posttest gains such as parent education, income levels, enrollment in other accelerated coursework, or outside activities.

Definitions

Critical Thinking – The definition of critical thinking developed by the American Philosophical Association Delphi Study will be utilized for this study. This report defines critical thinking as “the process of purposeful, self-regulatory judgment. This process gives reasoned consideration to evidence, context, conceptualizations, methods, and criteria.” (Facione, 1990c).

Inquiry. Inquiry represents the diverse ways in which scientists study the natural world, and propose explanations based on the evidence derived from their work (NRC 1996). As summarized in the description of inquiry in the *National Science Education Standard (NCES):*

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (NRC 1996, p. 23).

Classroom inquiry. For the purpose of this study, classroom inquiry is defined in alignment with the NCES. The five essential features of classroom inquiry are that the learner 1) engages in scientifically oriented questions; 2) gives priority to evidence in responding to questions; 3) formulates explanations from evidence; 4) connects explanations to scientific knowledge; and 5) communicates and justifies explanation

Inquiry pedagogy. A form of active learning that emphasizes questioning, data analysis and generation of *evidence-based explanations* - a "procedural way of knowing" (NCES, 2000.)

CHAPTER TWO

REVIEW OF THE LITERATURE

The literature review for this study has five sections: 1) critical thinking skills and dispositions; 2) inquiry definitions; 3) theoretical framework for inquiry learning; 4) curricular approaches for inquiry pedagogy and critical thinking; and 5) assessment of critical thinking and dispositions.

The first section provides an overview of the higher order cognitive skills which are the focus of this study, critical thinking and critical thinking dispositions. Included in this section is literature detailing the developments in defining critical thinking and dispositions beginning with the early work of Dewey (1910) through the landmark American Philosophical Association (APA) Delphi Study (Facione, 1990c), which established the common definitions of critical thinking and dispositions used in this study.

Section two reviews relevant literature concerning the definition of inquiry.

The third section reviews relevant literature concerning the conceptual and theoretical foundations for inquiry, beginning with the role of scientists, through how students learn, leading to the pedagogical approach utilized in the classroom (Minner, Levy & Century, 2009). Inquiry-based curriculum and instruction has been promoted in national documents for over twenty years (AAAS, 1993, 1998; NCTM, 1989, 1991, 2000; NRC, 1996, 2000), and continues to grow through 21st Century Skills and Common Core Standards that explicitly call for and integrate critical thinking skills as a means to achieving career and college readiness for all students. With foundations in the social constructivism of Schwab (1960), Ausubel (1963), Piaget (1970), and Vygotsky (1978), inquiry approaches emphasize that learning is constructed by an individual through active learning, organization of information and integration with or replacement of existing knowledge. This section also reviews the relevant literature detailing the development of curricular approaches to science and mathematics inquiry and critical thinking.

Section four provides an overview of the development of curricular approaches for inquiry pedagogy which promote critical thinking. This section reviews inquiry pedagogy practices which incorporate a number of strategies which, when placed at the forefront of pedagogical practice and curricular interventions, can result in improved critical thinking skills in students.

Section five discusses the purpose and methods of critical thinking assessment, particularly at the secondary school level where inquiry pedagogical approaches have been implemented.

Critical Thinking and Disposition

Critical thinking has been increasingly recognized as one of the essential components of education as well as a powerful resource in an individual's personal and civic life (Facione, Facione, & Giancarlo, 1996; Halpern, 1996). Since the early 1980's, educators and politicians have taken note of the centrality of critical thinking as an educational goal and outcome at the K-12 and postsecondary levels (Facione, 1990d,1990e; Halpern, 1996, Kuhn, 1990; Lipman,1987; Mayer, 1997; U.S. Department of Education, 1990). At the same time, efforts to define, teach and measure critical thinking have intensified (Jones, 1993; Kurfiss, 1988; Norris & Ennis, 1989).

Critical thinking is a complex concept in terms of its definition, measurement and place in the curriculum. It can be conceived of as both a skill and a disposition, as a stage in cognitive development as well as a goal in the educational process.

> The theoretical task for critical thinking is to offer a frame that is open-textured enough to accommodate the various disciplinary particulars, while offering enough of a unique framework to point the direction in which critical thinking instruction must look to identify appropriate curriculum content and classroom methodology. (Weinstein, 2003, p. 281).

Throughout the literature, researchers emphasize the link from theory to practice, and pose definitions of critical thinking in terms of particular skills and dispositions. Researchers have struggled to conceptualize critical thinking and in the process relied on the notion of what it means to think critically and on perspectives regarding the impetus for critical thought (Cromwell, 1992; Ennis, 1985; Facione, Facione & Sanchez, 1994; Paul, 1990). These definitions present a wide range of the level of complexity, are backed by common theoretical perspectives, and present differences in their associated skills and abilities.

John Dewey's work in the early twentieth century provided a baseline for critical thinking theory that has been repeatedly referenced by researchers. Dewey identified "learning to think" as a primary purpose of education in 1933 (Halpern, 2003). He defined critical thinking as the "active, persistent and careful consideration of a belief or supposed form of knowledge in light of the grounds that support it, and the further conclusions to which it tends" (Dewey, 1910). He also categorized thinking skills into sub processes of induction, deduction, judgment, the construction of meaning, abstraction and scientific thinking (Dewey, 1910).

Bloom's Taxonomy was created mid-century in order to promote higher forms of thinking in education, such as analyzing and evaluating, rather than just remembering facts (rote learning). The framework elaborated by Bloom (1956) consisted of six major categories: knowledge, comprehension, application, analysis, synthesis, and evaluation. The categories after knowledge were presented as "skills and abilities," with the understanding that knowledge was the necessary precondition for putting these skills and abilities into practice.

Lower-level thinking skills including knowledge, comprehension and application were categorized as those that could be accomplished by most individuals. The remaining tasks, analysis, synthesis and evaluation, utilized the most complex skills and became known in the hierarchy as higher-order thinking skills associated with critical thinking skills.

Historically, intelligence and ability tests used to identify hierarchical intelligence of gifted students have looked to identify these same higher-order thinking skills (Schugutensky, 2008). Educators have come to recognize a high score on an intelligence test as a demonstration of critical thinking skills (Kaplan, 1974; Stankov and Roberts, 2005)

Ennis (1985) defined critical thinking as "reflective and reasonable thinking that is focused on deciding what to believe or do" (p. 45). During his extensive career in researching this area, Ennis identified four sets of abilities with critical thinking: making inferences, establishing a base for inferences, decision-making and problem solving. In a similar vein Brookfield (1987) identified four components of critical thinking: identifying and challenging assumptions, challenging the importance of a concept, identifying and exploring alternatives, and reflective skepticism. Paul (1992) distinguishes between sophisticated and weak critical thinking: "if thinking is disciplined to serve the interest of a particular individual or group, to the exclusion of other relevant persons and groups, it is sophistic or weak-sense critical thinking. If the thinking is disciplined to take into account the interests of diverse persons or groups, it is fair-minded or strong-sense critical thinking."

According to Browne and Keeley (2002) critical thinking is a process that begins with an argument and progresses toward evaluation. The process is activated by three interrelated activities: asking key questions designed to identify and assess what is being said; answering those questions by focusing on their impact on stated inferences; and displaying the desire to deploy critical questions. Chaffee (2002) argues that critical thinking is used to organize experience, construct knowledge and develop a philosophy of life (p. 4).

By the latter part of the twentieth century, there were numerous researchers examining the nature, features, and processes of critical thinking from which central themes emerge (Brookfield, 1987; Browne & Keeley, 1990; Facione, 1992; Facione et al., 1995; McPeck, 1981; Paul, 1993). It is the conceptualization of critical thinking as consisting of the dimensions of cognitive skills and affective dispositions developed by a panel of experts (Facione, 1990c) that comprises the conceptual framework for this study.

In 1987 the American Philosophical Association (APA) appointed a panel of experts to undertake a two-year process to consider the status of the concept of critical thinking in education, and to develop a common definition of critical thinking. The work of this Delphi Project yielded a robust conceptualization of the intellectual skills as well as the motivational disposition involved in the critical thinking process (Facione, 1990c). Prior to the Delphi Project there were a number of recognized conceptualizations of critical thinking (Ennis, 1996; Paul, 1993; Mayer, 1997; Lipman, 1997; Norris, 1989; Swartz, 2003; Beyer, 1995; Sternberg, 2001), but no consensus among educators, researchers and philosophers on the definition of critical thinking, reflective thinking or higher-order thinking skills.

The APA Delphi Report defined critical thinking to be "purposeful, self-regulatory judgment which results in *interpretation, analysis, evaluation and inference*…" (Facione, 1990c. P. 3). This panel of experts found the skills aspect of critical thinking to include cognitive skills in six core areas: interpretation, analysis, evaluation, inference, explanation and self-regulation (Facione, 1990c). Definitions for these core areas can be found in Appendix A.

Facione (1990c) described critical thinking as a pervasive human phenomenon which is purposeful, reflective judgment focused on deciding what to believe or what to do. Each day individuals analyze information, interpret events and situations, evaluate claims and provide the reasons offered in their support. In each of these situations individuals analyze, interpret, evaluate, draw inferences and make reflective judgments about what to believe and what to do. These reflective judgments are the focus of critical thinking and also provide a transition into a discussion of the disposition toward critical thinking.

Although this definition focuses primarily on critical thinking skills, many experts agree that there is more to critical thinking than skill. There is a necessary attitude – dispositions – that reflect the decision to apply critical thinking in various situations (Dewey, 1938; Facione, Facione, & Giancarlo, 1995, 2000; Giancarlo & Facione, 2001; Halpern, 1996; Norris, 2003; Paul, 1990, 1992; Case, 2004). According to Cromwell (1992), "critical thinking is both a systemic inquiry and a mental attitude, a complex set of abilities and a process of dealing with ideas. Dewey (2010) expressed the significance of these "habits of mind." As Norris (2003) observed, an individual can have the ability to think critically and not exercise it under certain circumstances.

The second vital component of the APA Delphi Study (following the discussion and definition of critical thinking) was the discussion of the dispositional side of the critical thinker, which involves a consistent willingness, motivation, inclination and a drive to be engaged in critical thinking while reflecting on significant issues, making decisions, and solving problems (Facione et al., 1997; Facione et al, 1995). Individuals not disposed toward critical thinking may have the ability to think critically, but will not engage in this level of thinking unless forced to do so (Facione et al., 1997).

The Delphi project panel published a definition of the ideal critical thinker:

> The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing

> personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in selection of criteria, focused on inquiry, and persistent in seeking results which are as precise as the subject and circumstances of inquiry permit. Thus, educating good critical thinkers means working toward this ideal. (Facione, 1990c).

The APA Delphi Study also provides a definition of critical thinking dispositions that will be employed for this study. The study provides a set of characteristics defining the "ideal critical thinker" that includes, but is not limited to being "habitually inquisitive, well-informed, trustful of reason, open minded, flexible…" (Facione, 1990c, p.3). Facione and his colleagues characterized the disposition toward critical thinking as the consistent internal motivation to use critical thinking skills to decide what to believe or what to do (Facione, Facione & Giancarlo, 2000). According to Giancarlo and Facione (2001), seven dispositions have been directly connected with critical thinking: *truth-seeking*, *open-mindedness*, *analyticity*, *systematicity*, *confidence in reasoning*, *inquisitiveness,* and *maturity of judgment.* Definitions for these dispositions can be found in Appendix B.

Facione, Sánchez, Facione, and Gainen (1995) hypothesized three possible interactions between critical thinking skills and dispositions toward critical thinking. First, overall disposition toward critical thinking may nurture a student's decision to attempt to use critical thinking skills. As a result, successful use of critical thinking skills will then reinforce the student's disposition toward critical thinking. Second, there may be relationships between specific combinations of dispositions toward critical thinking and specific critical thinking skills. Third, a one-to-one connection may exist between each disposition toward critical thinking and each skill associated with critical thinking.

Halpern (1996) also addresses the necessity of having the appropriate attitude in order to become a critical thinker, suggesting that a strong critical thinker must exhibit the following six characteristics: a willingness to plan; flexibility; persistence; a willingness to self-correct; being mindful, and consensus-seeking.

Paul (1990) also recognizes that critical thinking is not limited to skill development, and is usually associated with traits of mind including intellectual humility, intellectual courage, intellectual perseverance, intellectual integrity, and confidence in reason.

In summary, critical thinking experts include both skills and dispositions in their definitions of critical thinking; they advocate for an understanding of why critical thinking is important, and why acquiring a set of beliefs and values as well as a set of skills will be useful as they continue the pursuit of knowledge both in college and beyond (Facione, Facione, & Giancarlo, 1996; Norris, 2003).

Inquiry Definitions

Based on the evidence as explained by the National Research Council (NRC), inquiry represents the diverse ways in which scientists study the natural world, and propose explanations based on the evidence derived from their work (NRC 1996). Inquiry refers to at least three distinct categories of activities: (1) What scientists do (i.e., conducting investigations using scientific methods) (2) How students learn (i.e., actively inquiring through thinking and doing into a phenomenon or problem, often mirroring the processes used by scientists) (3) The pedagogical approach that teachers employ (i.e., designing or using curricula that allow for extended investigations)

(Minner, Levy, & Century 2009). Inquiry itself, whether it is the scientist, student, or teacher who is doing or supporting inquiry, has several core components.

The NRC describes five core components from the learner's perspective as ‘‘essential features of classroom inquiry’’ (NRC, 2000, p.25):

(1) Learners are engaged by scientifically oriented questions.
(2) Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
(3) Learners formulate explanations from evidence to address scientifically oriented questions.
4) Learners evaluate their explanations in light of alternative explanations, those reflecting scientific understanding.
(5) Learners communicate and justify their proposed explanations.

Inquiry has been used to form curriculum goals, design instructional strategies, and assess learning (Chiappetta and Adams, 2004). This underscores the ongoing relationship between content and process in the curricular approaches to the development of science and mathematics inquiry skills. Inquiry is not a linear process -- rather, it unfolds through a process of questions followed by answers followed by more questions. At its core, in the classroom inquiry is “active learning processes in which students answer research questions through data analysis” (Bell, Smetana and Binns, 2005).

Theoretical Framework for Inquiry Learning

Concerned that science was being taught as “rhetoric of conclusions,” Joseph Schwab's work from the late 1950s into the early 1960s provided a foundation for the advent of inquiry as a major theme in curriculum reform. In his work, he argued that science itself had changed: the nature of science as inquiry controlled research. Schwab argued, moreover, for teachers to look to three levels of suggested inquiry in the laboratory as a model for science pedagogy. In a structured setting, instructional materials can pose questions and describe methods of investigation that allow students to discover relationships they do not already know; in a guided setting, the laboratory manual or textbook can pose questions, but the methods and answers are left open; in an open setting, students confront phenomena without questions based in textbooks or laboratories.

In the third setting, students engage in the most sophisticated form of inquiry as they are left to ask questions, gather evidence, and propose explanations based on their evidence. In addition, he proposed that students engage in conversations about interpretation of data, use of evidence, assumptions and explanations, and other issues of scientific inquiry (Schwab 1960).

Inquiry is rooted in the constructivist philosophy of learning. Constructivism, which is based on observation and scientific study about how people learn, includes aspects of the work of Jean Piaget (1970), Lev Vygotsky (1978), and David Ausubel (1963). These kinds of constructivism-based materials are classified as inquiry-based and include hands-on activities as a way to motivate and engage students while concretizing science concepts (Minner, Levy & Century, 2010).

According to Piaget, children and adults use mental patterns (schemes) to guide behavior or cognition, and interpret new experiences or material in relation to existing schemes (Piaget, 1978). For new material to be assimilated, however, it must first fit an existing scheme. Similarly, for Ausubel, meaningful information is stored in networks of connected facts or concepts referred to as schemata. New information, which fits into an existing schema, is more easily understood, learned, and retained than information that does not fit into an existing schema (Ausubel, 1963).

For Piaget and Ausubel, new concepts that are well anchored by or attached to existing schemata will be more readily learned and assimilated than new information relating to less established schemata. The same holds true for information not attached to any schemata at all (e.g., the case with compartmentalized, or rote learning).

Vygotsky's work supports a cultural basis of cognition and for the existence of a "zone of proximal development" which refers to the idea that there is a zone for each learner, which is bounded on one side by the developmental threshold necessary for learning and on the other side by the upper limit of the learner's current ability to learn the material under consideration (Vygotsky’s, 1978).

Constructivist approaches emphasize that knowledge is constructed by an individual through active thinking, organization, and integration with or in replacement of existing knowledge, and further emphasizes the importance of social interaction in the learning process (Cakir, 2008). Science and technology education literature indicates that teaching with a constructivist paradigm can contribute to effective teaching and learning, as well as generate high student motivation and critical thinking skills (Skemp, 1998). Constructivism as a theory of learning can provide the framework needed to help math teachers move from a transmission model to one in which the learner and the teacher work together to solve problems, engage in inquiry, and construct knowledge (Draper, 2002). The National Council of

Teachers of Mathematics (NCTM, 1989; 1991; 1995) recommends using a constructivist method of teaching, in which learners develop meaning based on experience and inquiry (White-Clark et al., 2008).

Draper described constructivism as "the philosophy, or belief, that learners create their own knowledge based on interactions with their environment including their interactions with other people" (2002, p. 522). Research suggests that constructivist math instruction improves secondary math learning (Grant, 1998). Constructivist math instruction, a research-based practice, encourages "content to self-connections and enhances student learning (White-Clark, et al., 2008). As a result, students better understand the relevance of mathematical concepts and become more motivated and interested in their math courses, thereby improving math performance and meeting the standards.

Curricular Approaches to Science and Mathematics Inquiry and Critical Thinking

It has been generally acknowledged that the ability to think critically becomes increasingly important to success in life as the pace of change, complexity and interdependence increase. Ennis (1989) proposed a critical thinking typology of four instructional approaches teaching critical thinking: general, infusion, immersion and mixed. In a general critical thinking course, critical thinking skills and dispositions are learning objectives without specific subject matter content. In this approach an instructor attempts to teach critical thinking abilities and dispositions separately from the existing subject matter offerings. While examples of this approach usually involve some content, there is not a requirement that the content be present.

Riesenmy, Mitchel, Hudgins and Ebel (1991) taught self-directed critical thinking using Ennis' 1989 general method to elementary school students in the St. Louis public schools. They found that students who were taught four modes of critical thinking performed better on a problem-solving posttest than students who did not receive this curricular intervention. Three groups of treated students outscored the control group, with the groups testing immediately after the intervention, four weeks later and eight weeks later.

In the infusion and immersion approaches, content becomes important: critical thinking is an explicit objective in the infusion course but not in the immersion course. According to Abrams, infusion of critical thinking requires deep, thoughtful and well-understood subject matter instruction in which students are encouraged to think critically in the subject being taught (Abrami, 2006). In this approach general principles of critical thinking skills and dispositions are made explicit. An infusion method in the Biology Critical Thinking Project examined the development of critical thinking skills in seventh-grade biology students (Zohar, Weinberger & Tamir, 1994). The experimental design was used to test the efficacy of the program; with scores for nearly 500 students, the results were highly favorable for the program in which students registered higher gain scores on both the biology critical thinking test as well as the general critical thinking test.

In the immersion approach subject matter is thought-provoking and students do get immersed in the subject; however, the general critical thinking skills are not made explicit. Kamin, O'Sullivan and Deterding (2002) used digital case presentations followed by group discussions as the instructional method. Two groups watched the recorded discussions, with one group discussing the case online and the second group participation in a face-to-face discussion. The third group discussed the case face-to-face after reading the text version. The findings of the study indicated that while the video presentation seemed to facilitate critical thinking, the online discussion scored the highest.

The fourth approach, mixed, is taught as an independent track with specific subject matter; it consists of a combination of the general approach with either the infusion or immersion approach. In this approach students receive subject-specific critical thinking instruction as well as a separate instruction which includes general critical thinking principles. McCarthy-Tucker (1998) implemented Ennis' mixed approach in examining high school freshmen and sophomores enrolled in English and algebra who received instruction in logic to supplement their curricular instruction. These students demonstrated much greater improvement that untreated control participants on a pretest-posttest study

Atkin and Karplus (1962) originally introduced inquiry curriculum based on the learning cycle as the 3E learning cycle with exploration, invention, and discovery phases. A number of the major theoretical models of inquiry instruction currently used in science are based on the 3E learning cycle (Leonard & Penick, 2009). Johann Herbart (1901). John Dewey (1910) provided the foundations for this instructional model.

Using Herbart's belief that the best pedagogy allows students to discover relationships among experiences, a teacher would introduce new ideas which connect with existing ideas in order to form concepts using a pedagogical approach of guiding, questioning and suggesting through indirect methods (Herbart, 1901). The teacher would complete this cycle with a generalization and application phase. Herbart's model is considered one of the first systematic approaches to teaching (Bybee et.al, 2006).

John Dewey, a science teacher by original training, was one of the first to observe that science education placed too much emphasis on the facts while placing little emphasis on science for thinking and developing habits of mind. Dewey, moving away from the "sage on the stage" model of teaching, encouraged science teachers to use scientific inquiry as a teaching strategy (Dewey, 1910).

During the curriculum reform of the late 1950s and early 1960s, a range of instructional models began to emerge. The shared interests of Atkin and Karplus in the teaching of science to children led in a model of guided inquiry (Atkin & Karplus, 1962) and resulted in a learning cycle that provided the foundation for the Science Curriculum Improvement Study (SCIS).

Bybee's Biological Sciences Curriculum Study (BSCS) 5E instructional model expanded the 3E model to five phases: engagement, exploration, explanation, elaboration, and evaluation phases (Bybee et. al, 2006). The 5E model is widely used in classrooms (BSCS and IBM, 1989), and has been shown to have a positive impact on science education (Bybee et al. 2006). This model also provides the curricular foundation for students to have the opportunity to construct their own knowledge and understanding (Yager 2000), to construct concepts and developing reasoning patterns (Lawson 2001), and to connect new knowledge to real life (Blank 2000). The model has been shown to be an extremely effective approach to learning (Lawson 1995) and is also supported by cognitive research on learning (Bransford, Brown and Cocking 1999).

Despite subtle differences between inquiry models -- like the number of steps or components associated with the range of inquiry models or how they are named -- a number of curriculum models exhibit some uniformity in what occurs in the inquiry instruction and learning (Marshall & Horton, 2011). Effective inquiry learning environments provide essential scaffolding based on each student's readiness and current ability and in challenging students to think critically and analytically (Marshall & Horton, 2011). The development of deep conceptual knowledge, rather than surface learning, is also commonly found in inquiry curriculum. Successful, well-planned inquiry leads to a deeper, more thoughtful interaction with underlying concepts (Donovan & Bradsford, 2005, NRC, 2000).

For some teachers the implementation of inquiry curriculum in the classroom falls somewhere along a continuum of four levels of inquiry and is distinguished in how those levels are implemented in the classroom. Although national and local standards can drive the content and identify *what* is crucial for students to learn, the teacher drives the decision on the particular emphasis and pedagogy that students will ultimately experience in the classroom. Recognizing this, researchers in the 1960s began efforts to categorize teacher's implementation of inquiry in the classroom. An early version of inquiry categorization is attributed to Schwab (1964), and was later modified by Herron (1971).

Most recently, Banchi and Bell (2008) proposed a four-level continuum for use by classroom teachers in classifying levels of inquiry instruction. The use of this continuum serves as a guide for teachers who need to provide classroom activities that will enable their students to develop inquiry abilities and understandings necessary to progress to a higher level of inquiry.

In the lowest level, confirmation inquiry, students are given a question and procedure (method), and the results are known in advance. Confirmation inquiry is often used when the goal is to reinforce a previously introduced idea or to introduce students to the experience of conducting an experiment. Closer in format to a cookbook-type lab, students are following an established procedure but they are recoding data and analyzing their data.

At the structured inquiry level, the questions and procedures are provided by the teacher, but students generate an explanation supported by their collected evidence. Also considered to be a lower-level inquiry process, structured inquiry serves an important purpose of enabling students to develop the skill sets necessary to conduct higher –level inquiry.

Guided inquiry occurs when the teacher provides students with the research question to stimulate inquiry, but students are self-directed in designing the procedures (method) and developing explanations. The teacher continues to play an active role in the classroom, responding to student questions and providing guidance as to the sense of student investigations.

Open inquiry represents the highest level of inquiry, and affords students the opportunity to develop questions themselves, develop procedures, carrying out experiments, and communicate the results. Students must be able to generate their own testable, topic-related questions and use their own procedures. Observation skills are especially crucial in open inquiry, along with teacher modeling on how to turn their observations into questions. Teachers who talk aloud with their students as they make observations and discuss emerging questions are modeling behavior for the students so that they will begin to generate their own questions from their observations (Martin-Hansen & Johnson 2006). Students must also be able to distinguish which questions are appropriate for inquiry investigations.

Although there is agreement among many science educators that that both guided and open inquiry can be efficient in developing inquiry skills and critical thinking, there is some debate as to which type of inquiry is more relevant to the teaching and learning facilities available in many high schools (Yerrick, 2000; Zion, 2007; Zion, Cohen, & Amir, 2007). Students in an inquiry classroom are afforded the opportunity to develop a hybrid of skills which represents the convergence of general critical thinking skills and science inquiry skills (Zohar, Weinberger & Tamir, 1994). Despite the convergence they do represent two distinct sets of skills.

Critical thinking has long been regarded as one of the major goals of education at all levels (Resnick, 1987). Past studies assessing critical thinking ability have revealed that students demonstrated very poor skills in tasks that require critical thinking (Jungwirth, 1985; Jungwirth & Dreyfus, 1990). In the 1960's students who were educated in the new inquiry-oriented science curriculum of the day performed no better than their traditional counterparts (Shulman & Tamir, 1973). It now appears that critical thinking does not develop in passing, but rather by way of explicit and direct efforts. Several studies have provided evidence that learning experiences explicitly designed to develop critical thinking achieve those goals to varying degrees

(Friedler & Tamir, 1986; Kaplan, 1967; Pappalis, Pohlman & Pappalis, 1908; Reif & St. John, 1979; Wheatley, 1975). Abrami et al (2008) conducted a meta-analysis of 117 empirical studies on the effects of instructional interventions on students' critical thinking skills and dispositions, finding that a substantial amount of the variation in effect sizes across studies was driven by pedagogical grounding and by the type of intervention.

Educators continue to debate the best approach for critical thinking skills as a result of two unresolved issues. First, to what extent are critical thinking skills general and content free versus content-specific; and second, to what extent and under which: circumstances does transfer of critical thinking take place. This produces a dilemma: should courses be designed to teach critical thinking as a general approach, or should educators infuse the development of critical thinking skills within discipline-specific courses (Ennis, 1989; McPeck, 1981; Resnick, 1987). Abrami et al. (2008) found that among categories of instruction including general, immersion, infusion, or mixed (Ennis, 1989), the studies with the mixed approach had the largest effect-sizes and the immersion approach had the smallest. Based on this finding, they recommended that educators should approach critical thinking instruction through the integration of critical thinking into regular academic content. In addition, the authors found that interventions in which educators received specific training had the largest effect sizes.

Infusion of critical thinking with regular disciplinary courses is rooted in the belief that general and domain-specific cognitive skills seem to interact in human cognition (Perkins & Salomon, 1989). Thinking strategies have been found to be dependent on the individual's extant theories and concepts (Kuhn, Amsel, & O'Loughlin, 1988; Kuhn, 1989). To hold this viewpoint calls for teaching critical thinking skills within a knowledge-rich environment, such as infusing the teaching of these skills into regular disciplinary science courses. This infusion approach may contribute not only to the development of thinking skills but to a better understanding of the discipline under study (Zohar, Weinberger & Tamir, 1994). These researchers noted that incorporating the teaching of critical thinking skills into the science curricula may decrease the reliance on rote memorization and enhance higher-order earning.

One argument commonly cited as a problem with the infusion approach focuses in the issue of transfer. If thinking skills cannot transfer from one content domain to another, on first glance it may be inefficient to teach these skills in a specific field as it does not contribute to overall student performance in other fields. However, studies in the late 1980's began to indicate that under certain conditions transfer of thinking skills can take place (Perkins & Salomon, 1989). These conditions include exposure to multiple examples in different content areas, with the learners formulating generalizations among the disciplines (Gick & Holyoak, 1987; Lehman, Lempert & Nisbet, 1988; Brown, Kane & Long, 1989).

Marzano (1993) analyzed procedures and practices in various critical thinking programs. He proposed three main categories: Questioning techniques, writing techniques and general information processing strategies. A small number of studies have focused on elementary students involved in science inquiry and critical thinking. In a study of Australian primary students, Boddy, Watson and Aubusson (2003) conducted a qualitative study of teachers' implementation of lessons using the "5 E's" model. Videotaped lessons were analyzed using observerable behaviors which determined lower-order and higher-order thinking skills based on observations. The findings of this study determined that the use of science inquiry significantly increased critical thinking skills in these students. Through the use of a case design study, Hapgood, Mafnusson and Sullivan-Palincsar (2004) determined the student level of engagement was high during a ten-day qualitative study of second grade students. In each of these studies, the use of science inquiry resulted in a positive effect on the critical thinking skills of elementary students.

Greenwald & Quitadamo (2014) identify inquiry-based teaching as a pedagogy designed to foster critical thinking; inquiry-based instruction in science courses can improve critical thinking skills (Ernst & Monroe, 2006; Quitadamo et al., 2008). Significant gains in critical thinking can occur in as little as nine weeks (Quintadamo & Kurtz, 2007).

Zohar and Dori (2003) examined four studies, each of which addressed a different project whose goal was to teach critical thinking in science classrooms. By the end of each of the four programs, students with high academic achievement gained higher thinking scores than their peers with lower academic achievement. However, students from both subgroups made considerable progress.

Current mathematics research and reform movements endorse inquiry-based, "guide on the side" instruction grounded in constructivist pedagogy (Gibson & Van Strat, 2001). Inquiry-based math instruction provides an opportunity for teachers to pose more questions rather than limit their instructions to a lecture format (Rogers, 2002). Burger and Starbird (2000) raised concerns concerning the mathematics community's previously limited understanding about the transformational process that mathematics can help students develop. They also emphasized the importance of the acculturation necessary to accept failure as a building block of learning in mathematics and inquiry learning. Mathematics pedagogy can enable students to learn to solve problems, analyze situations and sharpen their observations of the world. In addition, students must realize that their primary job is not simply to learn the solution to mathematics problems but to learn to think and develop habits of mind that are illustrated by mathematics (Nurger & Starbird, 2000).

Inquiry-based mathematics instruction develops independent problem-solving and critical thinking skills in students (Witt & Ulmer, 2010). The goal of inquiry learning should be to challenge students to engage in an activity that requires critical thinking and a reflective process of higher-order thinking skills (Lemlech, 1998).

Inquiry pedagogy does not prevent teachers from teaching directly during critical points in a lesson, but rather it allows mathematics teachers to vary instructional approaches and orchestrate the lesson in such a way as to help students discover and develop their own understanding of the concepts (Bush, 2006; Gagnon & Maccini, 2007). Inquiry mathematics pedagogy supports a problem solving and critical thinking process which allows students to utilize deeper levels of understanding and application beyond what traditional approaches have in the past (Goodrow, 2007; NCTM, 2000).

Research advocates for a focus on developing conceptual understanding of the mathematics as well as the ability to put mathematical ideas and skills to work in solving complex and relevant problems. Courses must attend to the process strands of critical thinking, reasoning, making connections, and communicating (NCTM, 2000).

Inquiry-based mathematics instruction improves student attitude and achievement, facilitates student understanding, fosters critical thinking skills, and facilitates mathematical discovery (Jarrett, 1997). Guidelines for creating an inquiry-based classroom that provide students with the time, space, resources, and safety necessary for learning include:

- Engaging students in designing the learning environment.
- Integrating science laboratories into the regular class day
- Using inquiry in the mathematics classroom
- Employing management strategies to facilitate inquiry
- Reflecting the nature of inquiry by displaying and demanding respect for diverse ideas, abilities, and experiences; modelling and emphasizing the skills, attitudes, and values of scientific inquiry: wonder, curiosity, and respect toward nature; enables students to have a significant voice in decisions about the content and context of their work; and nurtures collaboration among students (Jarrett, 1999).

From a practical standpoint and with an eye towards the skills necessary to survive in the 21st century, it appears that critical thinking can be taught in such a way that these skills will transfer across the curriculum and into a multitude of real world situations. Major changes in instruction are necessary to shift the emphasis from rote learning and passive application to the use of effective critical thinking as the primary tool of learning (Ben-Chiam, Ron, & Zoller, 2000). Having identified the development of higher-order cognitive skills as a major purpose in science education, Zoller (1987, 1993, and 1999) further makes the case for the teaching and development of critical thinking in science education at all levels.

Inquiry pedagogy incorporates a number of strategies which, when placed at the forefront of pedagogical practice and curricular interventions, can result in improved critical thinking skills in students. Strategies such as those described below can be incorporated into teacher practice as well as into rubrics to be used for student grown and assessment.

- In an inquiry classroom active learning in a group setting provides students with an opportunity to enhance their critical thinking skills by learning from and being accountable to each other (Gokhale, 1995; Quitadamo et al., 2008; Greenwald & Quitadamo, 2014).
- Students can demonstrate the use of critical thinking skills when they are expected and encouraged to generate their own questions (Potts, 1994; Madhuri, Kantamreddi & Goteti, 2012).
- Teachers probe students' thinking through the use of open-ended questions in the classroom, which tend to make students think more analytically and use critical thinking skills (Potts, 1994; Quitadamo & Kurtz, 2007; Hackling, Smith & Murcia, 2010).
- The transfer of critical thinking skills can be promoted by linking a newly acquired skill to other situations or experiences encountered by the student (Halpern, 1998; Zoller, 2000; Ben-Chaim, Ron, & Zoller, 2000).

- As teachers promote the use of evaluative skills they encourage the use of reasoning, argument analysis and scientific analysis (Fitzgerald, 2000; Halpern, 1998, 1999; McCall, 2011).
- Teachers who promote decision-making and problem solving encourage the development of the ability to judge between alternatives in a problem situation (Halpern, 1998; Lrynock & Robb, 1999).
- Teachers who promote problem-solving skills as an integral part of mathematics provide students with frequent opportunities to formulate, grapple with and solve complex problems, and enable students to apply and adapt the strategies learned to other problems in other contexts (NCTM, 2000).
- By solving mathematical problems, students acquire critical thinking skills, habits of persistence and curiosity, and confidence in unfamiliar situations that serve them well outside the mathematics classroom (NCTM, 2000).

The literature suggests that by infusing critical thinking and dispositions into the context of science and mathematics curriculum, the inquiry-based pedagogy has the potential to take student learning and thinking to a level wherein the instructor fosters the development of both critical thinking skills and dispositions that will enable students to gain success in learning in today’s classrooms as well as in their future personal lives and professional careers.

Assessment of Critical Thinking Skills and Dispositions

The definition of critical thinking in this study was developed by the American Philosophical Association (APA) as a Delphi research study for determining core critical thinking, based on the consensus of experts from the United States and Canada. These experts represented disciplines in the humanities, sciences, social sciences and education. The APA Delphi Report defined critical thinking as the process of purposeful, self-regulatory judgment.

In addition to defining critical thinking the APA also defined a person disposed toward critical thinking as someone who demonstrates “positive critical spirit, a probing inquisitiveness, a keen sense of mind, a zealous dedication to reason and a hunger or eagerness for reliable information” (Facione, 1990c). Further critical thinkers “approach specific issues, questions or problems with clarity in stating the question or concern, orderliness in working with complexity, diligence in seeking relevant information, reasonableness in selecting and applying criteria, care in focusing attention on the concern at hand, persistence through difficulties are encountered, precision to the degree permitted by the subject and circumstances”(Facione, 1990c).

An examination of the list of thinking skills that constitute critical thinking (Norris & Ennis, 1989) reveals a partial overlap with scientific inquiry skills (Schwab, 1962; Shulman & Tamir, 1973; Tamir & Lunetta, 1978). It is not surprising to find that issues such as testing hypotheses, planning experiments and drawing conclusions can be found on lists of both critical thinking skills and science inquiry skills (Zohar, Weinberger & Tamir, 1994).

With a well-reasoned definition in place, experts began to discuss purposed and methods of critical thinking assessment. Ennis (1992) proposed seven major purposes for critical thinking assessments:

- Diagnosing the levels of students' critical thinking levels;
- Giving students feedback about their critical thinking;
- Motivating students to be better at critical thinking;
- Informing teachers about the success of their efforts to teach students to think critically
- Doing research about critical thinking instruction questions and issues;
- Providing help in deciding whether a student should enter an educational program
- Providing information for holding schools accountable for the critical thinking prowess of their students

Critical thinking is not just about factual answers or information learned, but rather these assessments are about how students think and reason (Facione, 1989; Ruggiero, 1988). Facione described the heart of critical thinking as process not content, with research supporting the fact that standardized tests are not sensitive to variations in the process of critical thinking skills (Marzano & Costa, 1988). According to Suzuki and Valencia (1997), the best predictor of learning is in fact the learning itself, not the accumulated knowledge.

Although critical thinking assessments have been used diagnostically, many of those assessments have not reflected classroom instructional goals, curriculum or content (Norris & Ennis, 1989). Sternberg (1997) argues that assessment of student abilities, intelligence, and thinking must be contextualized to the learning environment and the individuals. He reported significant student gains in critical thinking when critical thinking was part of the curriculum and not an addendum (Sternberg, 1977). Sternberg advocated for open-ended tests as a means for measuring higher-level thinking skills in contrast with the closed assessments adopted under NCLB (2002) or assessments which rely on objective, quantitative measures (Marzano, 2003a).

Standardized tests that do focus on the theoretical concepts of critical thinking can be used to measure critical thinking (Ruggiero, 1998)). Many of the tests available in the past have been in multiple-choice format, and those tests have been presented in the context of general knowledge rather than being subject-specific (Facione, 1989; Ruggiero, 1989; Norris, 1989, Ennis, 1993). Facione (1989) and Norris (1989) both provided lists in the late 1980's of commercially available tests based on general knowledge that are comprehensive in nature and measure a range of critical thinking skills. Norris (1989) advocated for the general approach for testing critical thinking skills so as not to penalize learners for lacking specific facts from certain subjects. Norris also supported the educational goal that critical thinking skills should transfer as much as possible from an isolated learning or testing environment to applications in everyday life.

Ennis (2009) has provided an updated list within the past five years which includes two instruments from the California Critical Thinking Skills assessments: the California Critical Thinking Skills Test and the California Critical Thinking Dispositions Inventory. Facione developed these instruments, maintaining his finding that if constructed carefully a multiple choice format for testing critical thinking can overcome the problems of content and construct validity.

The California Critical Thinking Skills Test (CCTST) and the California Critical Thinking Disposition Inventory (CCTDI) were selected as standardized measurements for this study because they were directly conceptualized and derived from the American Philosophical Association (APA) Delphi report (Facione, 1990c). Critical thinking in this study is defined using the APA Delphi definition of critical thinking. This comprehensive definition recognizes the complexity of thinking required in studying discipline related content. The CCTST and CCTDI were developed and tested to evaluate the skills identified in the Delphi report (Facione, 1990c).

Ben-Chiam, Ron & Zoller (2000) used the California Critical Thinking Disposition Inventory to assess the disposition of Israeli eleventh-grade students toward critical thinking according to school type, science level, and gender. Their findings support the establishment of a baseline reference for the disposition toward critical thinking of high school science students, and the reliable use of the CCTDI in future research aiming at evaluating the effectiveness of critical thinking and higher order cognitive skills oriented instructional goals.

In a previous Israeli study, Zohar, Weinberger and Tamir (1994) conducted a study of 678 seventh grader students randomly assigned to two groups using the same biology textbook. The treatment group participated in the Biology Critical Thinking Project in which carefully designed activities for developing critical thinking skills were incorporated into the curriculum. Two parallel forms of a General Critical Thinking Skills Test were used to assess performance in seven critical thinking skills. The results of this study indicated that the treatment group improved in their critical thinking skills when compared to their own initial level and to their counterparts in the control group.

Summary

Critical thinking involves both cognitive skills and dispositions; results in interpretation, analysis, evaluation and inference; and involves a consistent willingness, motivation, inclination and drive to be engaged. Secondary school leaders are faced with the challenge of providing rigorous coursework which imparts core content knowledge as well as vital critical thinking skills. In the science classroom, 21st century students need to be engaged in learning about the nature and practice of inquiry through careful scaffolding and self-directed research. In the mathematics classroom, expansion of instructional practice to include pedagogy emphasizes strategies of critical thinking and analysis which teach students to solve problems, analyze situations, and sharpen the way they look at the world. Research during the past twenty years suggests that inquiry pedagogy is more likely to develop in students the ability to evidence a higher level of conceptual knowledge as well as a higher level of critical thinking skills and dispositions. There is a need for additional research designed to assess the effect of inquiry pedagogy on the critical thinking skills and dispositions of high school students. This study may provide data that will guide educators in curriculum planning and pedagogical practice.

CHAPTER THREE

METHODOLOGY

This chapter describes the methodology used to collect and analyze the data for this study and is organized as follows: the purpose and research questions are stated; a brief statement of the curricular intervention is provided; an explanation of the study's research designed is provided; the population and sample are described; the selection and rationale for the instrumentation is described; finally, the process of data collection and analysis is detailed.

Purpose and Research Questions

The purpose of this study was to determine whether student participation in an inquiry-based curricular program contributes to statistically significant differences in pre-post test scores in critical thinking skills and dispositions. To achieve the purpose of this study two research questions were posed to determine the extent to which the curricular intervention accounts for differences in pre-post-test scores for the California Critical Thinking Skills Test (CCTST) and the California Critical Thinking Dispositions Inventory (CCTDI).

1. Are there statistically significant differences in pre- and post-test scores in critical thinking scores for students participating in an inquiry-based curricular program?

2. Are there statistically significant differences in pre-and post-test scores in critical thinking disposition scores for students participating in an inquiry-based curricular program?

Curricular Intervention

A large public school district in the mid-Atlantic region began discussions in 2002 concerning the development of an inquiry-based, interdisciplinary science and math program which would integrate the 21^{st} century critical thinking skills necessary to prepare students for success in an ever-changing world.

To implement this vision, a curriculum was designed around a number of critical thinking skills including analytical reasoning, inference, evaluation, interpretation and explanation. As the program entered its tenth year in fall 2014, school leadership also focused on several dispositional skills which appear to be crucial for success including open-mindedness, inquisitiveness, confidence in reasoning, and a willingness to look for the truth in any situation. The key difference in this program however, is not the curriculum but the pedagogy – the manner in which material is presented.

From day one in ninth grade, teachers and students partnered in these inquiry classrooms are challenged to ask questions, make observations, seek out information, plan and design, collect data with selected tools, analyze and interpret data, explain and share findings. Keeping with the notion that inquiry is not a linear process -- the content in this curriculum is not presented in a linear fashion but rather it unfolds through a process of questions followed by answers followed by more questions. The students in this inquiry setting are challenged in such a way that the search for answers draws upon students' prior knowledge and understanding (Bransford, Brown and Cocking, 2000).

Students in this program participate in a guided/open inquiry setting, as described in the literature review section, where the teacher defines the knowledge framework where inquiry is conducted, but leaves the students to select a wide variety of inquiry questions. Students investigate topic-related questions that are student-formulated through student designed/selected procedures. The students make their own decisions throughout each stage of the inquiry process. The teachers' ability to motivate their students to ask those questions that will guide them in their inquiry is one of the most important components in implementing this pedagogy (Chin & Chia, 2004). In keeping with the research students in these inquiry-based classrooms are encouraged to ask questions, provide better explanations, demonstrate understanding of more content, provide supporting evidence for their claims, collaborate more productively and effectively with one another, and actively monitor and evaluate their own work (Kolodner et al. 2003; White and Frederiksen 1998).

The faculty have been afforded the opportunity to assess how they teach; to examine their beliefs about how children learn; to identify their strengths and weaknesses as a teachers; and to develop a trusting relationship where this team of teachers can professionally share and discuss their students' work as well as their own professional development. The importance of teacher assessment in inquiry pedagogy has been addressed in similar settings by researchers who have developed assessments of inquiry-based instruction that reflect what teachers do in the classroom while providing both a benchmark and a guide to improving the quality of inquiry implemented in their classrooms (Marshall, Horton & White, 2009).

In concert with the school director, faculty have participated in an ongoing professional development plan that has enabled them to gain new inquiry strategies and improvement in performance through continuous practice and reflection. Developing inquiry pedagogical skills involves a lengthy trial-and-error phase that requires patience and persistence. Student inquiries need constant refining; teachers will find themselves constantly trying a new investigation, noting what went well and then planning what to do differently the next time. Teachers are also looking to draw upon students' prior knowledge and understanding (Bransford, Brown, & Cocking, 2000) while enabling the students to perform in the region of their brain where they can be challenged to think critically without being overwhelmed (Vygotsky, 1978).

The inquiry pedagogy used by this faculty to deliver the integrated science and mathematics courses in this program supports the development and use of critical thinking skills. These skills, as described below, are consistent with those measured by the CCTST, which is one of the instruments to be used in this study. Faculty are mindful of these skills and their role in student growth. Careful consideration is given to identification of the critical thinking skills necessary for success in each new reading, lab activity, writing assignment and classroom activity.

- Students use *analysis* skills to gather information from charts, graphs, diagrams, spoken language and documents, attending to patterns, details, and elements of particular situations. The use of analytical reasoning skills in the development and execution of lab work enables students to identify assumptions, reasons and claims while examining how they interact in the formation of arguments.

- Students use *inference* skills to draw conclusions from reasons and evidence, and to offer hypotheses.
- Students use *evaluation* skills to assess the credibility of sources of information and the claims that they make.
- Students use *deductive reasoning* skills to make decisions where rules, operating conditions, core beliefs, values, procedures and terminology can determine outcomes in the context of the development and execution of lab work.
- Students use *inductive reasoning* skills to draw inferences about what they believe to be true based on prior experiences, simulations, data analyses, hypotheticals, patterns, and experiences.
- Students use *interpretative* skills to determine the precise meaning and significance of sets of data, charts, and spoken words.
- Students use *explanatory reasoning* skills to make final decisions about what to believe or what to do in a particular circumstance or experiment. The ability to explain the evidence, reasons, methods, or rationale for decisions and conclusions enables students to discover, test and articulate the reasons for beliefs and decisions.

Faculty are also looking for the willingness of students to be disposed toward the use of critical thinking skills is as an important consideration in the integrated science courses. These skills, as listed below, are also consistent with those measured by the CCTDI, which is one of the instruments to be used in this study.

- Students able to demonstrate the disposition toward *truth-seeking* always desire the best possible understanding of a situation. These students ask tough questions and strive not to allow bias or preconception color their search for knowledge and truth.
- Students who demonstrate the disposition toward *open-mindedness* act with tolerance, allowing classmates with opposing views to voice their ideas freely and participate in open discussion.
- Students who demonstrate *analyticity* anticipate potential consequences of what may happen next, including outcomes of situations, choices, proposals and plans.
- Students who are able to approach problems in a discipline, orderly and systemic manner demonstrate *systematicity*. They are not as likely to zone in on a particular strategy or approach as much as they are likely to be organized and orderly in their approach.
- The ability to demonstrate *confidence in reasoning* enables a student to trust reflective thinking to solve problems and make decisions.
- Students who are *inquisitive* demonstrate the tendency to want to know things even if they are not immediately apparent. They are both eager and patient in their learning.
- Students who demonstrate *maturity of judgment* are able to see the complexity of multiple issues while striving to make timely decisions.

The inquiry-based curriculum and teaching techniques emerge in the classrooms in this program are based on constructivist learning theories. Classroom learning for these students has become a process rather than a specific set of structured lessons. Learning is enhanced through increased student involvement, multiple ways of knowing, and carefully sequenced scaffolding. The knowledge resulting from student-derived investigations is more relevant and meaningful, particularly in relationship to the expectations of a 21st century school. The investment in the curriculum and learning process by both parties – teacher and student – leads to active construction of knowledge rather than passive transmission of facts from the lecturer. Faculty plan weekly in grade-level teams, and are mindful of insertion of curricular activities which develop specific critical thinking skills. Specific examples of critical thinking skill applications infused in the science curriculum can be found in Appendix C.

Research discussed in the literature review chapter has shown that inquiry-based pedagogy is more likely to develop the ability to evidence a higher level of conceptual understanding, to develop a much richer and more flexible array of knowledge, and to develop critical thinking skills. Anecdotal observations of the inquiry pedagogy implemented at this magnet school suggest possible gains in critical thinking skills and dispositions, but research is necessary at this school to measure student gains in the critical thinking skills and dispositions inherent in this process. Appropriate assessment options are necessary in order for this program to continue to be funded and to serve as a model for science education at the secondary level.

Study Design

In this single group pretest-posttest research design archival data was used to determine whether student participation in an inquiry-based curricular treatment resulted in pre-post test differences in critical thinking skills and critical thinking dispositions. The design is considered non-experimental since it does not involve assignment of subjects to conditions. Rather, the researcher used the archival data from a single group of subjects tested before and after a period of exposure to treatment, in this case an integrated science and mathematics curriculum delivered using inquiry pedagogy. This is a basic design often chosen for its simplicity and ease of application. A single pretest observation is taken on a group of respondents (O_1), treatment (X) then occurs, and a single posttest observation on the same measure (O_2) follows:

$$O_1 \quad X \quad O_2$$

Adding the pretest provides limited information about the counterfactual inference concerning what might have occurred to the participants without the treatment; however, because O_1 occurs before O_2 the two may differ for reasons unrelated to treatment including maturation or history (Shaddish, Cook & Campbell, 2002).

History refers to "all events that occur between the beginning of the treatment and" the posttest that could have produced the observed outcome in the absence of that treatment" (Shaddish, Cook & Campbell, 2002). Time passes during the course of any experiment, and events can occur that unduly influence the outcome beyond the experimental treatment. Plausibility of history can be reduced in this research as the treatment is limited to a specific group of ninth graders who will experience similar events throughout the year of treatment and who will be administered the pre- and post-tests at the same time.

The participants were all ninth grade students in a large suburban school district, and were all enrolled in ninth grade for the first time (i.e. no repeat students). Students attending this program also attend their home high schools on alternating days where they are be likely to be enrolled in other honors level courses with district mandated curricula in English, social studies, and the second or third year of a world language.

With reference to maturation, participants in research projects experience many natural changes that would occur even in the absence of treatment (Shaddish, Cook & Campbell, 2002). Changes such as growing older, stronger, wiser, or more experienced naturally occur even in the absence of treatment. For example, normal cognitive development ensures that students improve their cognitive performance over time. Although students in this study did grow older during the course of this research study, they were roughly the same age and experienced the same maturational processes.

The pretest-posttest design involves two measurements of the dependent variable surrounding, in time, the administration or occurrence of a single treatment. Subjects serve as their own control, and comparisons are made before and after treatment. Researchers make the assumption that the differences between pretest and posttest are due to the effects of the treatment that occurred in between (Spector, 1981).

This is a simple design often used for program evaluation where the goal is to determine the effectiveness of a particular program, particularly when an appropriate comparison group is unavailable (Spector, 1981). The design is, however, sometimes sensitive to instrument reactivity and Hawthorne effects.

With no comparison group it may be difficult to separate the effects of measurement of knowledge of being in an experiment. The mere knowledge that one is in a study may affect behavior or a subject may be affected by pretests in such a manner as to influence their reactions to the treatment. Subjects may also adapt to being in a study, however, and provide more natural responses after a period of adjustment.

The independent variables were the pre-test scores in critical thinking and pre-test scores in critical thinking disposition. The dependent variables were post-test scores in critical thinking and post-test scores in critical thinking disposition (post-CCTDI).

Study Population and Sample

The targeted population for this study included all ninth grade students entering a math and science magnet program in the fall of 2014, a number totaling 67. Students were offered admission to this program through a competitive process during the eighth grade year. Students were selected on the basis of a holistic review of their application, standardized test scores, writing prompts, middle school transcript, teacher recommendations, and personal essays.

The 2013-14 admissions cycle offered enrollment to 13 percent of applicants. The PSAT was employed as the standardized test instrument for admission. The mean PSAT Math score for admitted students was 66, placing this group of twelve to thirteen year old students in the 97th percentile when compared with high school sophomores. The demonstrated strength of the population sample factored into the selection of the test instruments for this study. Although Insight Assessment offers a critical thinking test for middle-school age students as part of their family of critical thinking skills instruments, that instrument was judged to be a less challenging instrument for this population sample. In concert with conversations with the staff at Insight Assessment the researcher choose the CCTST and CCTDI as it was judged to be a challenging but not overwhelming instrument for students at this demonstrated academic level.

Based on the distribution of the overall score percentiles for the test takers in this group, as compared to an aggregate sample of CCTST Four Year College Students, the average percentile score for this group of test takers was 71 for pre-test scores, and 74 for post-test scores. With overall CCTST mean scores of 81.2 at pre-test and 82.6 at post-test, the scores of this group of test-takers indicate critical thinking skills that are superior to the vast majority of test-takers and are designated as Superior scores according to assessment recommendations provided in the 2015 CCTST User Manual (2015). In short, this group of test-takers was already quite strong at the point of the pre-test, while still leaving room for growth.

Instrumentation

The California Critical Thinking Skills Test (CCTST) and the California Critical Thinking Disposition Inventory (CCTDI) were selected as standardized measurements for this study because they were directly conceptualized and derived from the American Philosophical Association (APA) Delphi report (Facione, 1990), and they measure the extent to which student critical thinking skills are impacted by the program's pedagogical approach. Critical thinking in this study was defined using the APA Delphi definition of critical thinking elaborated on in Chapter One of this study. This comprehensive definition recognizes the complexity of thinking required in studying discipline related content. The CCTST and CCTDI were developed and tested to evaluate the skills identified in the. Delphi report (American Philosophical Association, 1990c).

California Critical Thinking Skills Test (CCTST), (Facione & Facione, 2010)

The California Critical Thinking Skills Test (CCTST) is designed to permit test-takers to demonstrate the critical thinking skills required to succeed in educational or workplace settings where solving problems and making decisions by forming reasoned judgments are important. One point is given for each correct answer; a higher score means better ability in critical thinking.

The CCTST is composed of multiple choice questions requiring a range of critical thinking skills including analyzing the meaning of a sentence, drawing the correct inference from a set of assumptions, or evaluating objections to stated inferences. Different questions progressively invite test-takers to analyze or to interpret information presented in text, charts, or images; to draw accurate and warranted inferences; to evaluate inferences and explain why they represent strong reasoning or weak reasoning; or to explain why a given evaluation of an inference is strong or weak.

All versions of CCTST (a five scale and an enhanced seven scale version) provide an array of scale scores describing strengths and weakness in various skill areas. This research utilized the online, seven-scale version of the test, which provides scores for the individual core critical thinking skills of: *Analysis, Inference, Evaluation, Induction, Deduction,* and *Overall Reasoning Skills,* plus scores for *Interpretation and Explanation.* The subscales are identified in the Delphi Report (APA, 1990), described in the CCTST Test Manual (Facione, 2014), and defined in Appendix A of this study.

According to the CCTST manual (Facione, 2013) the CCTST is specifically designed to measure the skills dimension of critical thinking. The CCTST was previously available in three forms: Form A, Form B, and Form 2000. The newest version, the CCTST-10.1.10, is a standardized 34-item multiple choice test developed by Dr. Peter Facione and is based on the American Philosophical Association's Delphi Panel consensus of the conceptualization of critical thinking known as the Delphi Report of 1990 (APA, 1990). Items on the CCTST were derived based on the consensus report of 46 experts who comprised the Delphi Panel.

The Form 10.1.10 is an improved version of Form 2000. The reported correlation scores between Form 10.1.10 and Form 2000 is .91. Form 10.1.10 can be used with its companion instrument, the CCTDI, Form 92.1.92, which will also be used in this study. The researcher selected Form 10.1.10 of the CCTST to be used in this study because Form 10.1.10 has established validity and reliability and is most commonly used in critical thinking research studies. Based on recommendations for studies which will employ both the CCTST and the CCTDI in research, the CCTDI was administered first (Facione, 2014). The CCTST is a challenging cognitive measure and, when administered first, may affect students' disposition towards critical thinking. Therefore, in this study the CCTDI was administered followed by the CCTST.

Reliability and validity testing for the CCTST has been established through research efforts which began in the 1970's. The items in the CCTST are drawn from a pool of over 200 items developed during more than three decades of research aimed at validity and reliability. Form 10.1.10 is an updated, "more robust" version of the earlier CCTST, Forms A (1990), B (1992), and Form 2000 (2009) (Facione & Facione, 2002). In addition to other item formats, this newer version requires students to use information presented in charts and diagrams to answer questions.

Test retest reliability for the instrument meets or exceeds .88 in samples where the administration conditions are adequately controlled at pretest and posttest. Testing instruments sold by Insight assessment have met the threshold for strong internal consistency reliability (a minimum of Alpha of 0.80 for attribute measures and a minimum KR-20 of .72 for skills measures) for their Overall scores, and are observed to maintain this performance in all samples of adequate variance.

The CCTST does not test any content area, but rather challenges test-takers to form a reasoned judgment based on a short scenario presented in each question item.

Each question item provides all the information necessary to answer the question correctly. In short, because the CCTS measures only critical thinking and not content knowledge, it makes it possible to use this instrument as a pretest and posttest to measure changes that occur in critical thinking during an educational intervention.

Facione (1997) found that regression analysis on CCTST scores of students who: had taken a critical thinking course indicated that “71% of the variance in CCTST post-test scores can be predicted by a combination of SAT-verbal, SAT-math, college GPA and the CCTST pre-scores ($\rho = .001$). Removing the CCTST pre-test from the analysis produced a regression model which predicted 41% of the CTS post-test variance on the basis of a combination of SAT-verbal, SAT-math, college GPA and high school GPA ($\rho = .001$)” (Facione & Facione, 2002, p.21).

The California Critical Thinking Disposition Inventory (CCTDI)

The California Critical Thinking Disposition Inventory (CCTDI); Facione, Facione, and Giancarlo (2000) is another measure that grew out of the Delphi report on critical thinking (American Philosophical Association, 1990). Individuals with a positive disposition toward critical-thinking are open-minded, eager to learn, organized in approach in problem solving, confident in their reasoning skills and prudent in their decision making. These individuals use reason and evidence, and search for the “best knowledge” (Facione et al, 2000).

The instrument consists of a 75-item attitudinal measure, and is aimed for use with college-age students. The students were asked to rate each item on a 6-point Likert scale from strongly agree to strongly disagree. Scores are reported for the seven subscales and the eighth score is the report on an overall CT score. Disposition was calculated by summing the scores from each of the subscales. The CCTDI measures seven characteristics: truth-seeking, open-mindedness, analyticity, systematicity, self-confidence in critical thinking, inquisitiveness and maturity of judgment. Definitions of these subscales are provided in Appendix B of this study. Individuals with higher scores in al CCTDI scales demonstrate a greater disposition to use critical thinking skills. Scores of at least 40 out of 60 on the subscales and 280 out of 420 are indicative of an individual with positive habits (Facione, 2000). Form 92.1.92 of the CCTDI was used for this study.

All versions of CCTDI (a five scale and an enhanced seven scale version) provide an array of scale scores describing strengths and weakness in various skill areas. This research utilized the online, seven-scale version of the test, which provides scores for the individual core critical thinking disposition scores of *truth-seeking, open-mindedness, analyticity, confidence in reasoning, inquisitiveness, maturity of judgment*, and an overall score. The subscales are identified in the Delphi Report (APA, 1990), described in the CCTDI Test Manual (Facione, 2013) are defined in Appendix B.

The CCTDI measures the seven constructs of disposition discussed previously along with the overall CT disposition score that is computed with equal contributions of each scale. There are a total of 75 items (9 to 12 questions for each scale) that use a Likert type scale, with answers (1) disagree strongly, (2) disagree (3) disagree marginally (4) agree marginally (5) agree and (6) strongly agree. For each scale, an individual's score can range from 10-60, for a total possible score for all 7 scales to be 420. A total score of <280 is said to denote a weakness in CT disposition and a total score >350 indicates a strength in CT disposition. For individual scales, a score greater than 40 is interpreted as a positive inclination to critically think. For scores less than 30, a negative tendency to critically think and a score in between (31-39) an ambivalent inclination. Alpha reliabilities for the CCTDI scales ranged from .71 to .80; alpha reliability for the total score on Facione's pilot study was .91 (Facione, Facione & Giancarlo, 2001, p.5). Subsequent studies on the CCTDI provided further empirical evidence of internal reliability with an alpha of .90 for the overall score and scale scores ranging from .60 to .78 (Facione, Facione & Giancarlo, 2001, p.5).

Data Collection

The Institutional Review Board for the Social and Behavioral Sciences approved the research protocol on June 3, 2015 (Appendix D).

The researcher sought permission from the school division (Appendix E) to access the archival data results from pre- and post-testing of ninth grade students enrolled in a math and science magnet program in a large suburban school district during the 2014-2015 academic year. Personnel in that school oversaw the administration of two instruments, the California Critical Thinking Skills Test (CCTST) and the California Critical Thinking Dispositions Inventory (CCTDI), administered in pre-test and post-test fashion during the 2014-2015 academic year. The researcher requested access to the archival relevant scores for the 67 students who participated in this study with all students coded by the school to prevent identification of individual students.

Data Analysis

Descriptive statistics including minimum, maximum, mean, standard deviation, and variance are provided for all variables. The study utilized paired t-tests and a repeated measures Multivariate Analysis of Variance (MANOVA) to evaluate differences among group means. Use of MANOVA enabled the measurement of several dependent variables in a single experiment, enabling a better chance of discovering which factor is truly important. In addition MANOVA can protect against Type I errors that might occur if multiple ANOVA's were conducted independently. Secondly, rather than using the F value as the indicator of significance a multivariate measure, Wilks' lambda, was used. Wilks' lambda demonstrates the amount of variance accounted for in the dependent variable by the independent variable; the smaller the value, the larger the difference between the groups being analyzed.

Peter Facione, one of the authors of the CCTST and CCTDI, has suggested that operative relationships might occur between specific combinations of critical thinking dispositional attributes and specific sets of critical thinking skills (Facione, 1995). For example, previous research suggests that open-mindedness and inquisitiveness might lead to interpretive and analytical questions (Facione, 1995). Faculty at the school whose archival data is to be used have identified several dispositions and skills as crucial to success in a number of the instructional components of the ninth grade course. The use of a Repeated Measures MANOVA as a data analysis in this study enabled the researcher to explore which of the sub-scales may be driving any of the significant differences or influences in critical thinking dispositions or skills.

CHAPTER 4

DATA PRESENTATION AND ANALYSES

This chapter reports the data findings of the study and is organized to present the data in the following manner: 1) descriptive statistics, 2) data from the paired t-tests; and 3) data from the repeated measures multivariate analysis of variance (MANOVA).

The purpose of this study was to determine whether student participation in an inquiry-based curricular program contributes to statistically significant differences in pre-post test scores in critical thinking skills and dispositions. To achieve the purpose of this study the following two research questions were posed:

1. Are there statistically significant differences in pre- and post-test scores in critical thinking scores for students participating in an inquiry-based curricular program?
2. Are there statistically significant differences in pre-and post-test scores in critical thinking disposition scores for students participating in an inquiry-based curricular program?

As detailed in Chapter 3, the CCTST and CCTDI measure critical thinking skills and dispositions not content knowledge, making it possible to use these instruments as a pretest and posttest to measure changes that occur in critical thinking skills and dispositions as the result of a curricular intervention.

The archival data used for this study included complete data for 64 students who completed pre- and post- testing on both instruments. The CCTST reports scores on seven subscales of critical thinking; the CCTDI reports scores on seven subscales of critical thinking dispositions. In total, the archival data included 14 pre-test and 14 post-test scaled scores for a relatively small group of subjects.

Descriptive Statistics

Table 1 reports descriptive statistics for the 64 students who completed the pre- and post-testing in the study, and includes the mean, standard deviation, and standard error for the pre- and post-test sub-scale scores for the CCTST.

Pre-test means for the seven CCTST sub-scales ranged from 79.2 to 85.9; post-test means ranged from 79.8 to 86.8. Of the seven sub-scale scores for critical thinking, the largest change occurred in the deduction subscale with a difference of 2 point between pre- and post-test. The scores for interpretation, evaluation and induction skills increased by less than one point, while the mean scores in analysis and inference skills increased by less than 2 points. There was a .2 point decrease in pre-post test scores for explanation skills.

Standard deviation scores indicate that the range for pre-post test scores for interpretation skills narrowed, while the range of pre-post test scores for evaluation, explanation, and induction widened.

Table 1
Descriptive Statistics for CCTST pre-post test Means

Skills	***M***	***N***	***SD***	***SE***
Analysis_pre	82.8	64	7.86	.98
Analysis_post	84.3	64	7.99	.99
Interpretation_pre	85.9	64	9.26	.15
Interpretation_post	86.7	64	7.30	.91
Inference_pre	83.3	64	6.62	.82
Inference_post	85.1	64	6.38	.79
Evaluation_pre	79.1	64	6.91	.86
Evaluation_post	80.0	64	9.30	1.16
Explanation_pre	80.0	64	8.46	1.05
Explanation_post	79.8	64	9.75	1.21
Induction_pre	83.5	64	6.41	.80
Induction_post	84.3	64	7.21	.90
Deduction_pre	81.3	64	6.27	.78
Deduction_post	83.3	64	6.61	.82

Table 2 reports descriptive statistics for the 64 students who completed the pre- and post-testing in the study, and includes the mean, standard deviation, and standard error standard for the pre- and post-test sub-scale scores for the CCTDI.

Pre-test means for the seven CCTDI subscale ranged from 36.7 to 48.5; post-test means ranged from 38.2 to 48.7. Of the seven sub-scale scores for critical thinking disposition, positive change ranging from .1 to 1.5 occurred four sub-scales: truth-seeking, open-mindedness, maturity of judgment, and inquisitiveness. A decrease in pre-post means was observed for analyticity, systematicy and confidence in reasoning.

Table 2
Descriptive Statistics for CCTDI pre-post test Means

Dispositions	***M***	***N***	***SD***	***SE***
Truth-seeking_pre	36.7	64	5.12	.64048
Truth-seeking_post	38.2	64	5.46	.683200
Open-mindedness_pre	44.7	64	3.46	.43315
Open-mindedness_post	45.6	64	3.67	.45880
Inqusitiveness_pre	48.3	64	5.14	.64333
Inqusitiveness_post	48.6	64	5.40	.67622
Analyticity_pre	46.0	64	4.63	.57970
Analyticity_post	45.8	64	4.64	.58044
Systematicy_pre	39.7	64	5.25	.65626
Systematicy_post	39.6	64	5.83	.72938
Confidence in reasoning_pre	45.6	64	4.53	.56704
Confidence in reasoning_post	45.5	64	4.60	.57555
Maturity of judgement_pre	44.0	64	4.49	.56155
Maturity of judgment_post	44.1	64	5.86	.73357

The standard deviation indicates that the range for pre-post test sub-scale disposition scores remained relatively unchanged, with the exception of a widening of sub-scale scores for maturity of judgement.

Two-tailed *t*-tests

A two-tailed *t*-test was run on the pre-post test scores for each of the seven sub-scales of the critical thinking skills and each of the pre-post test scores for the seven sub-scales of dispositions to determine the extent to which student participation in an inquiry-based curricular treatment accounts for change in pre-test *"thinking scores* and post *disposition* scores.

Table 3

Two-tailed t-test for pre-post Critical Thinking Skills

Skills	***M***	***SD***	***SE***	***t***	***df***	***p***
Analysis	-1.5	8.58	1.07	-1.45	63	.150
Interpretation	-.8	9.04	1.13	-.71	63	.475
Inference	-1.7	6.24	.78	-2.28	63	.026
Evaluation	-.9	7.75	.96	-.95	63	.345
Explanation	.1	10.19	.27	.12	63	.903
Induction	-.7	5.47	.68	-1.16	63	.249
Deduction	-2.0	6.09	.76	-2.68	63	.009

Research Question 1: Are there statistically significant differences in pre- and post-test scores in critical thinking scores for students participating in an inquiry-based curricular program? Table 3 shows the data for the paired samples t-tests for the seven sub-scales of the CCTST.

Although the significance level for pre-post test scores for the critical thinking skills of *inference* and *deduction* are below .05, as more tests are conducted the likelihood that one or more are significant just due to chance (a Type I error) increases. Correcting for the possibility of a familywise error (FWE) represents the probability that any one of a set of comparisons or significance tests is a Type I error. Dividing the significance level of .05 by 7 sub-scales in the "family" results in a confidence level of .007. Using .007 as the significance level, no statistically significant differences were observed between subscale scores at pre- and post-test for critical thinking skills.

Table 4

Two-tailed t-test for pre-post test Critical Thinking Dispositions

Dispositions	***M***	***S***	***SE***	***t***	***df***	***p***
Truth-seeking	-1.5	4.47	.55	-2.68	63	.009
Open-mindedness	-.9	3.82	.47	-1.89	63	.063
Inquisitiveness	-.3	4.65	.58	-.56	63	.574
Analyticity	.1	4.47	.55	.31	63	.759
Systematicy	.1	5.05	.63	.17	63	.863
Confidence in reasoning	.07	3.73	.46	.17	63	.868
Maturity in judgment	-.04	4.49	.56	-.08	63	.934

Research Question 2: Are there statistically significant differences in pre-and post-test scores in critical thinking disposition scores for students participating in an inquiry-based curricular program? Table 4 shows the data for the seven sub-scales of the CCTDI.

Similar to the critical thinking skills pre-post test scores, the significance level for pre-post test scores for the critical thinking disposition of *truth-seeking* is below .05, as more tests are conducted the likelihood that one or more are significant just due to chance (a Type I error) increases. Correcting for the possibility of a familywise error (FWE) represents the probability that any one of a set of comparisons or significance tests is a Type I error. Dividing the significance level of .05 by 7 sub-scales in the "family" results in a confidence level of .007. Using .007 as the significance level, no statistically significant differences were observed between subscale scores at pre- and post-test for critical thinking dispositions.

Repeated Measures MANOVA

As detailed in the previous section, the two-tailed t-test scores revealed that no statistically significant differences were observed between subscale scores at pre- and post-test for critical thinking skills and dispositions. In order to utilize additional appropriate statistical analysis to further evaluate the data, the researcher considered two sources for guidance in selection of data for further evaluation: research available in the literature and observations of the teachers who delivered the curricular intervention for the students in the group which provided the archival data.

Peter Facione, one of the authors of the CCTST and CCTDI, led a growing consensus in the mid-nineties that a complete approach to developing students into good critical thinkers must include the nurturing of the disposition toward critical thinking. Researchers debated whether cultivating the dispositional traits must precede implanting the skills while a developmental perspective would suggest that skills and dispositions should be mutually reinforced and taught.

Several studies suggested that operative relationships might occur between critical thinking dispositional attributes and critical thinking, as well as specific combinations of critical thinking dispositional attributes and specific sets of critical thinking skills. Giancarlo and Facione (1994) found a positive correlation($r=.41$) between CCTST and CCTDI among 193 high school sophomores. This study suggested that up to 16.8 % of the variance in skill test score was attributable to disposition test score; in addition they found that disposition was attributable to critical thinking skills. Colucciello's (1997) study also showed critical skills and disposition had significant correlation of .318 in a sample of 328 nursing students, with 9% of variance in critical thinking skills associated with overall critical thinking dispositions. Facione and Facione's (1997) research also reported that the correlation between critical thinking skills and disposition was significant ($r=.21$, p, $p<.001$) based on 1557 nursing students' CCTDI and CCTST scores.

These studies prompted additional questions about the relationship between critical thinking skills and dispositions. Facione & Facione (1997) examined the relationships among 35 pairs (5 critical thinking skills × 7 dispositions) by 1325 to 1428 students' cases. The result indicated the higher critical thinking skill scores were related to the stronger dispositions in 33 pairs. As examples of paired combinations, previous research suggests that *open-mindedness* and *inquisitiveness* might lead to *interpretive* and *analytical* questions (Facione, 1995).

In addition, faculty at the school whose archival data was used in this study were interviewed for the purpose of obtaining their observations on particular critical thinking skills and dispositions observed in the classrooms. Based on their work in the classrooms with the students in this study, teachers identified two skills *(interpretation* and *analysis*) and two dispositions (*open-mindedness* and *inquisitiveness*) as crucial to success in a number of the curricular components of the ninth grade course.

Two Repeated Measures MANOVA analyses were run in pairs as identified by the researcher through the literature and through observations from teachers who delivered the curricular intervention. The first pairing was the critical thinking skill of analysis and the disposition of inquisitiveness. The second pairing was the critical thinking skill of interpretation and the disposition of open-mindedness. The researcher used a multivariate analysis of variance (MANOVA) following the General Linear Model procedures of the Statistical Package for the Social Sciences (SPSS, ver. 22.0). An alpha level for testing the hypotheses was established a priori as $p < .05$. Selected critical thinking subscale skills and dispositions were tested using a two-way MANOVA.

The first analysis was run using pre-post data for the pair of the critical thinking skill of analysis and disposition of inquisitiveness. Identified as one of the critical thinking-disposition pairs in the literature review and in discussions with the faculty of the school from which the data was obtained, this analysis was run to determine the extent to which student participation in an inquiry-based curricular treatment accounts for change in post-test scores in analysis and inquisitiveness.

Table 5 reports the results of the Repeated Measures MANOVA for analysis and inquisitiveness.

Table 5

Repeated Measures MANOVA for Analysis and Inquisitiveness

Effect		**Value**	**F**	***df***	***p***	η_p^2
time	Pillai's Trace	.040	2.592	63	.112	.04
	Wilks' Lambda	.960	2.592	63	.112	.04
	Hotelling's Trace	.041	2.592	63	.112	.04
	Roy's Largest Root	.041	2.592	63	.112	.04
test	Pillai's Trace	.941	1012.068	63	.000	.94
	Wilks' Lambda	.059	1012.068	63	.000	.94
	Hotelling's Trace	16.065	1012.068	63	.000	.94
	Roy's Largest Root	16.065	1012.068	63	.000	.94
time*test	Pillai's Trace	.015	.952	63	.333	.015
	Wilks' Lambda	.985	.952	63	.333	.015
	Hotelling's Trace	.015	.952	63	.333	.015
	Roy's Largest Root	.015	.952	63	.333	.015

The overall test effect for time*test was not significant: Wilks' Lambda = .985, F (1, 63) = .95, $p > .05$. This indicates that the interaction effect of primary interest in this study was not significant.

The overall test effect for time was not significant: Wilks' Lambda = .96, F (1, 63) = 2.6, $p > .05$. This non-significant finding repeats previously reported *t*-test findings that pre- and post-tests results were similar.

The overall test effect for test was significant: Wilks' Lambda = .06, F (1, 63) = 1012.07, $p < .05$. This significant result reflects that the differences between condition means are not likely due to change and more likely due to the curricular intervention. The increased mean scores on the analysis and inquisitiveness subscales indicate that there is a change in analysis skills based on an increased disposition toward inquisitiveness.

The second analysis was run using pre-post data for the pair of the critical thinking skill of interpretation and the disposition of open-mindedness. Identified as one of the critical thinking skills-dispositions pairs in in the literature and in discussions with the faculty of the school from which the data was obtained, this analysis was run to determine the extent to which student participation in an inquiry-based curricular treatment account for change in post-test scores in interpretation and open-mindedness.

Table 6 reports the results of the Repeated Measures MANOVA for open-mindedness and interpretation.

Table 6

Repeated Measures MANOVA for Interpretation and Open Mindedness

Effect		**Value**	**F**	***df***	***p***	η_p^2
Time	Pillai's Trace	.029	1.853	63	.18	.03
	Wilks' Lambda	.971	1.853	63	.18	.03
	Hotelling's Trace	.029	1.853	63	.18	.03
	Roy's Largest Root	.029	1.853	63	.18	.03
test	Pillai's Trace	.970	2070.914	63	.000	.97
	Wilks' Lambda	.030	2070.914	63	.000	.97
	Hotelling's Trace	38.872	2070.914	63	.000	.97
	Roy's Largest Root	38.872	2070.914	63	.000	.97
time*test	Pillai's Trace	.000	.006	63	.938	.000
	Wilks' Lambda	1.000	.006	63	.938	.000
	Hotelling's Trace	.000	.006	63	.938	.000
	Roy's Largest Root	.000	.006	63	.938	.000

The overall test effect for time*test was not significant: Wilks' Lambda = 1.0, F (1, 63) = .006, $p > .05$. This indicates that the interaction effect of primary interest in this study was not significant.

The overall test effect for time was not significant: Wilks' Lambda = .97, F (1, 63) = 1.85, $p > .05$. This non-significant finding repeats the *t*-test findings that pre- and post-tests were similar.

The overall test effect for test was significant: Wilks' Lambda = .03, F (1, 63) = 2070.9, $p < .05$. This significant result reflects that the differences between condition means are not likely due to change and more likely due to the curricular intervention. The increased mean scores score on the critical thinking skills subscale and the critical thinking disposition subscale indicate that there is a change in interpretation skills based on an increased disposition toward open-mindedness.

CHAPTER FIVE

SUMMARY, DISCUSSION OF FINDINGS, AND CONCLUSIONS

Chapter Five is organized in five sections: 1) a review of the purpose and problem, and rational of the study and. 2) a summary of the relevant literature and, 3)a summary of the study methodology, and 4) findings by research questions and a discussion of those findings and, 5) recommendations for practice and future research.

Review of the Purpose, Problem and Rationale

The purpose of this study was to determine the extent to which student participation in an inquiry-based curricular treatment contributes to a change in disposition toward critical thinking and critical thinking skills.

The problem from which this purpose evolved concerned the need to integrate 21st century skills including critical thinking into the curriculum in order to provide the opportunity for students to gain deep content knowledge while developing the ability to apply this knowledge within and across disciplines (Daud & Husin, 2004; Silva, 2009; Sternberg, 2009).

Although the enactment of the United States Department of Education's No Child Left Behind Act (NCLB) moved the states to establish academic standards and testing systems to meet the federal accountability requirements measured in the form of Adequate Yearly Progress (AYP), the focus was on measurement of content competencies rather than the critical thinking skills necessary for success in the 21st century (Conley, 2007; Silva, 2008: Zhao, 2007).

In contrast to NCLB, The Partnership for 21st Century Skills has developed a plan for a unified, collective vision for 21st century learning that includes core subjects, 21st century content, and specific life and learning skills including critical thinking learning (Hardy, 2007, p. 20).

As a result of two reform initiatives at odd with each other, conscientious school leaders face the challenge of responding simultaneously to calls to increase critical thinking skills while still meeting AYP testing targets set by NCLB. Aware that the measure of success for tomorrow's students will be their ability to solve complex problems instead of simply memorizing algorithms and definitions (Friedman, 2005: National Academy of Sciences, 2005; National Council of Teachers of Mathematics, 2000), these same leaders are concerned about international test data indicates that the nation's schools have not been successful in teaching most students to become better critical thinkers or problem solvers (TIMSS, 2013; PISA, 2012; Grigg, Lauko & Brocway, 2006; Lee, Grigg & Dion, 2007; USDOE, 2007, 2012),

Research suggests inquiry learning as a pedagogical practice which has been shown to teach critical thinking skills; promote the transfer of concepts to new problem questions; teach students how to learn and builds self-directed learning skills; and develop student ownership of their inquiry and enhances student interest in the subject matter (Eslinger et al., 2008). Compared with those in non-inquiry settings, students in inquiry-based classrooms ask more questions, provide better explanations, demonstrate understanding of more content, are more likely to provide supporting evidence for their claims, collaborate more productively and effectively with one another, and are more prone to actively monitor and evaluate their own work (Kolodner et al. 2003; White and Frederiksen 1998).

By placing critical thinking and dispositions in the context of integrated science and mathematics courses, the inquiry-based pedagogy can aim to take student learning and thinking to a level wherein the instructor fosters the development of both attitudes and skills that will enable students to gain success in learning. Evidence from secondary-school science and mathematics studies lend support to the influence of an inquiry-based learning in both content areas (Laursen et al., 2014). Bybee et al. 2006; Yager 2000; Lawson, 2001; Greenwald & Quitadamo, 2014; Ernst & Monroe, 2006; Quitadamo et al., 2008.

Peter Facione, who has been one of the leaders in the effort to define and implement assessment measures for critical thinking skills and dispositions, has presented a body of research spanning a twenty-five year period which has been applied to multiple settings including attempts to understand the effect of a curricular intervention – inquiry pedagogy – on the critical thinking and dispositions of students in a wide range of academic programs and levels.

In order to reach greater clarity on these issues and in order to substantiate the impact of critical thinking as an outcome of inquiry pedagogy on the curriculum, the literature suggests the need for additional research on inquiry pedagogy that aims to promote the development, assessment, and measurement of changes in critical thinking skills (Phillips, Chestnut, and Respond, 2004; Ball & Garton, 2005).

The following questions guided the investigation:

Research Question 1: Are there statistically significant differences in pre- and post-test scores in critical thinking scores for students participating in an inquiry-based curricular program?

Research Question 2: Are there statistically significant differences in pre- and post-test scores in critical thinking disposition scores for students participating in an inquiry-based curricular program?

Summary of the Relevant Literature

Critical thinking has been increasingly recognized as one of the essential components of education as well as a powerful resource in an individual's personal and civic life (Facione, Facione, & Giancarlo, 1996; Halpern, 1996). The literature details developments in defining critical thinking and dispositions beginning with the early work of Dewey (1910) through the landmark American Philosophical Association (APA) Delphi Study (Facione, 1990c), which established the common definitions of critical thinking and dispositions used in this study.

Dewey's work is considered a starting point for the conceptual and theoretical foundations for inquiry, beginning with the role of scientists, through how students learn, leading to the pedagogical approach utilized in the classroom (Minner, Levy & Century, 2009). The literature details inquiry-based curriculum and instruction which has been promoted in national documents for over twenty years (AAAS, 1993, 1998; NCTM, 1989, 1991, 2000; NRC, 1996, 2000), and continues to grow through 21st Century Skills and Common Core Standards that explicitly call for and integrate critical thinking skills as a means to achieving career and college readiness for all students.

With foundations in the social constructivism of Schwab (1960), Ausubel (1963), Piaget (1970), and Vygotsky (1978), inquiry approaches emphasize that learning is constructed by an individual through active learning, organization of information and integration with or replacement of existing knowledge. The literature describes constructivism as a theory of learning which can provide the framework needed to help teachers move from a transmission model to one in which the learner and the teacher work together to solve problems, engage in inquiry, and construct knowledge (Draper, 2002).

The literature suggests that inquiry pedagogy practices which incorporate a number of strategies which, when placed at the forefront of pedagogical practice and curricular interventions, can result in improved critical thinking skills in students. John Dewey, a science teacher by original training, was one of the first to observe that science education placed too much emphasis on the facts while placing little emphasis on science for thinking and developing habits of mind.

The literature also details a number of studies in which the use of inquiry in science and mathematics courses resulted in a positive effect on students' critical thinking skills (Marzano, 1993; Boddy, Watson and Aubusson, 2003; Hapgood, Mafnusson and Sullivan-Palincsar, 2004; Greenwald & Quitadamo, 2014; Ernst & Monroe, 2006; Quitadamo et al., 2008; Quintadamo & Kurtz, 2007; Zohar and Dori, 2003; Gibson & Van Strat, 2001; Nurger & Starbird, 2000; Witt & Ulmer, 2010; Lemlech, 1998; Jarrett, 1997

With an eye towards the skills necessary to survive in the 21st century, the literature suggests that critical thinking can be taught in such a way that these skills will transfer across the curriculum and into a multitude of real world situations. Major changes in instruction are necessary to shift the emphasis from rote learning and passive application to the use of effective critical thinking as the primary tool of learning, further making the case for the teaching and development of critical thinking in science education at all levels. (Ben-Chiam, Ron, & Zoller, 2000; Zoller, 1987, 1993, and 1999)

The literature details a number of instructional strategies which can be incorporated into teacher practice as well as into rubrics to be used for the grown and assessment of critical thinking skills (Gokhale, 1995; Quitadamo et al., 2008; Greenwald & Quitadamo, 2014, Potts, 1994; Madhuri, Kantamreddi & Goteti, 2012, Quitadamo & Kurtz, 2007; Hackling, Smith & Murcia, 2010; Zoller, 2000; Ben-Chaim, Ron, & Zoller, 2000; Fitzgerald, 2000; Halpern, 1998, 1999; McCall, 2011; Lrynock & Robb, 1999; NCTM, 2000).

Development and implementation of new pedagogical practice must be accompanied by a similar process with assessment tools. The literature reports that experts began to discuss purpose and methods of critical thinking assessment during the mid to late- twentieth century, with Ennis (1992) proposing seven major purposes for critical thinking assessments. The literature describes these assessments as not a measure of how students think and reason rather than a measure of factual answers or information learned (Facione, 1989; Ruggiero, 1988). Facione described the heart of critical thinking as process not content, with research supporting the fact that standardized tests are not sensitive to variations in the process of critical thinking skills (Marzano & Costa, 1988).

The literature reports that while critical thinking assessments have been used diagnostically, many of those assessments have not reflected classroom instructional goals, curriculum or content (Norris & Ennis, 1989). Sternberg (1997) argues that assessment of student abilities, intelligence, and thinking must be contextualized to the learning environment and the individuals. He reported significant student gains in critical thinking when critical thinking was part of the curriculum and not an addendum (Sternberg, 1977). Sternberg advocated for open-ended tests as a means for measuring higher-level thinking skills in contrast with the closed assessments adopted under NCLB (2002) or assessments which rely on objective, quantitative measures (Marzano, 2003a).

Ennis (2009) provided an updated list which includes two instruments from the California Critical Thinking Skills assessments: the California Critical Thinking Skills Test and the California Critical Thinking Dispositions Inventory. Facione developed these instruments, maintaining his finding that if constructed carefully a multiple choice format for testing critical thinking can overcome the problems of content and construct validity.

The California Critical Thinking Skills Test (CCTST) and the California Critical Thinking Disposition Inventory (CCTDI) were directly conceptualized and derived from the American Philosophical Association (APA) Delphi report (Facione, 1990c). Critical thinking in this study is defined using the APA Delphi definition of critical thinking, which recognizes the complexity of thinking required in studying discipline related content. The CCTST and CCTDI were developed and tested to evaluate the skills identified in the Delphi report (Facione, 1990c).

The literature reveals studies which have used the CCTST and the CCTDI to assess critical thinking skills and dispositions of high school students, establish of a baseline reference for the disposition toward critical thinking of high school science students, and lay the groundwork for reliable use of the CCTST and CCTDI in future research aiming at evaluating the effectiveness of critical thinking and higher order cognitive skills oriented instructional goals. (Ben-Chaim, Ron, and Zoller, 2000; and Zohar, Weinberger and Tamir, 1994). These studies are examples of carefully designed activities for developing critical thinking skills which were incorporated into the curriculum, with the results indicating that the treatment group improved in their critical thinking skills when compared to their own initial level and to their counterparts in the control group.

Summary of the Study Methodology

In this single group pretest-posttest research design, archival data was used from a single ninth-grade class of 64 students enrolled in a math and science magnet school in the mid-Atlantic region.

The CCTST and CCTDI were employed. The unit of analysis was the class. The school conducted a pre- and post-test survey of all ninth grade students using the CCTST and CCTDI during the 2014-15 academic year; the pre-test was administered in September 2014 and the post-test was administered in late April 2015. The researcher sought and received permission to access archival data from the test results for 64 ninth grade students who serving as the sample in this study.

Descriptive statistics were reported. Paired t-tests and a repeated measures MANOVA were used to answer the research questions.

Findings and Discussion

The study findings are organized by research question. Following the research questions the findings discussed in detail.

Findings

Research Question 1: Are there statistically significant differences in pre- and post-test scores in critical thinking scores for students participating in an inquiry-based curricular program?

Although the paired t-test results indicated a significance level for pre-post test scores for the critical thinking skills of *inference* and *deduction* below .05, the researcher corrected for the possibility of a familywise error (FWE) by dividing the significance level of .05 by 7 sub-scales in the "family" resulting in a confidence level of .007. Using .007 as the significance level, no statistically significant differences were observed between subscale scores at pre- and post-test for critical thinking skills.

Research Question 2: Are there statistically significant differences in pre-and post-test scores in critical thinking disposition scores for students participating in an inquiry-based curricular program?

Although the paired t-test results indicated a significance level for pre-post test scores for the critical thinking disposition of *truth-seeking* is below .05, the researcher corrected for the possibility of a familywise error (FWE) by dividing the significance level of .05 by 7 sub-scales in the “family” results in a confidence level of .007. Using .007 as the significance level, no statistically significant differences were observed between subscale scores at pre- and post-test for critical thinking dispositions.

With seven sub-scales being considered in each of two analyses and a small sample size (n=64), the researcher took a conservative approach to the statistical analysis of the pre-post test sub-scale means for critical thinking skills and dispositions in light of familywise error (FWE), also known as alpha inflation or cumulative Type I error. Familywise error represents the probability that any one of a set of comparisons or significance tests is a Type I error. As more tests are conducted, the likelihood that one or more are significant just due to chance (Type I error) increases.

Additional Findings

Repeated Measures MANOVA were run for two sets of skills an dispositions identified through a review of the literature and conversations with the teachers of the class whose archival data was used for this study.

The analysis of the subscale scores for the critical thinking skill of analysis and the disposition score for inquisitiveness revealed no significance difference in pre-post test scores and no significance difference based on the time*test interaction. The analysis did reveal a significance for test, reflecting that the differences between condition means are more likely due to the curricular intervention. The increased mean scores score on the critical thinking skills subscale and the critical thinking disposition subscale indicate that there is a change in analysis skills based on an increased disposition toward inquisitiveness as a result of the curricular intervention.

The analysis of the subscale scores for the critical thinking skill of interpretation and the disposition of open-mindedness revealed no significant difference pre-post test scores and no significant difference based on the time*test interaction. The analysis did reveal a significant difference for test reflecting that the differences between condition means are likely due to the curricular intervention. The increased mean scores score on the critical thinking skills subscale and the critical thinking disposition subscale indicate that there is a change in interpretation skills based on an increased disposition toward open-mindedness as a result of the curricular intervention.

Discussion

The purpose of this study was to determine the extent to which student participation in an inquiry-based curricular treatment contributes to a change in disposition toward critical thinking and critical thinking skills.

The paired t-tests used to answer the research questions and to address the study purpose demonstrated no significant gains in critical thinking skills and dispositions. This study used a small, non-random sample at one institution. The small sample size of 64 students is one likely reason that the findings were not statistically significant.

Additional analysis using repeated measures MANOVA for two sets of critical thinking skills and dispositions revealed increased post-test scores in analysis and inquisitiveness as the result of the curricular intervention, and increased post-test scores in interpretation and open-mindedness as a result of the curricular intervention.

While these findings may not be generalizable as only one grade level was studied, they do inform the researcher about the link between theory and practice as they capture a picture of what was occurring the four classrooms of the 64 students in the ninth grade class in this study.

Based on the distribution of the overall score percentiles for the test takers in this group, as compared to an aggregate sample of CCTST Four Year College Students, the average percentile score for this group of test takers was 71 for pre-test scores, and 74 for post-test scores. With overall CCTST mean scores of 81.2 at pre-test and 82.6 at post-test, the scores of this group of test-takers indicate critical thinking skills that are superior to the vast majority of test-takers and are designated as Superior scores according to assessment recommendations provided in the 2015 CCTST User Manual (2015). In short, this group of test-takers was already quite strong at the point of the pre-test, while still leaving room for growth.

The CCTDI contains 75 Likert scale items and presents a score for each of the seven scales previously described in the Methodology section of this study. Scale scores in the 40-49 range indicate consistent endorsement and valuation of the attribute being measured, which was the case for the mean scores for five out of seven attributes measured in this study. Scale scores in the 30-39 range indicate consistent opposition or weakness in relation to the given attribute, which was the case for only two out of the seven attributes measured in this study. Overall this group of test-takers demonstrated strong evidence of dispositional skills while leaving room for growth.

There was a heavy reliance in this study on consistent teacher training. Although all of the teachers have participated in similar professional development and ongoing training in inquiry pedagogy, the study did not include any controls for teacher competency, and it was difficult to know whether each teacher implemented the pedagogy in exactly the same way. In addition, it was also difficult to know whether any of the teachers may have strayed significantly from the school norm of inquiry pedagogy.

The study did not control for a number of other variables that may be related to pre- and posttest gains such as parent education, income levels, enrollment in other accelerated coursework, or outside activities.

The study was limited to less than a full academic year, with the pre-test occurring in early September (at the beginning of the first quarter) and the post-test in late March (at the conclusion of the third quarter). This limited time period may not have allowed sufficient time for the curricular intervention to result in significant change in critical thinking skills and dispositions.

Although the students may have begun at a similar point in terms of student achievement and standardized testing scores presented for admission to this program, the study did not account for test preparation that might have accounted for higher standardized test scores at the time of admission.

For this study, individual students' scores were not the subject but rather the scores of the class as a whole were considered (the mean scores for the seven sub-scales for the CCTST and CCTDI) as this was the more appropriate reflection of the effect of the pedagogical intervention. Although the research questions were answered concerning the group using quantitative analysis, qualitative measures such as questionnaires, student journals or teacher journals may shed additional light on student growth.

Recommendations for Practice and Future Research

Recommendations for Practice

The research for the past three decades around 21st century skills calls for pedagogy and curricula which develop the ability of students to think critically in order to be prepared to compete for employment in a global economy. Efforts to find a balance between content and critical thinking pose a challenge for educators, but research suggests that this challenge for practice is not insurmountable and can have significant effects. While the results from this study may not be generalizable to other groups, it does present information about implementation and assessment of a curricular model geared towards developing in students the ability to think critically.

Teaching that supports the development of critical thinking skills has become a cornerstone of every major educational objective for the past thirty years (Quitadamo & Kurtz, 2007). Despite collective calls for enhanced critical thinking skills (Tsui, 1998, 2002), there remains a need for research-supported teaching and learning practices to help students better develop critical thinking skills necessary for success in the 21st century.

Halpern (1998) offers evidence of several problem-solving instructional programs aimed at improving critical thinking skills and abilities of college students. Kennedy et al. (1991) also reported that instructional interventions aimed at improving students' critical thinking skills have generally shown positive results. Finally, in a meta-analysis of 117 empirical studies examining the impact of instructional interventions aimed on students' critical thinking skills and dispositions, Abrami et al. (2008) found that these interventions, in general, have a positive effect, reporting a mean effect size of 0.34. They also reported that the distribution of effect sizes was homogenous, varied dramatically by type of intervention and sample characteristics, and was found to be higher in K-12 settings than in undergraduate settings.

The inquiry curricular treatment intervention in this study falls within the category of an immersion approach, where students are engaged in deep subject-matter instruction where critical thinking skills are acquired by students as a natural consequence of engaging in the subject matter (Ennis, 1989). The research also suggests that successful interventions of this nature may require professional development for teachers specifically focused on teaching critical thinking (Abrami et al., 2008).

Action research can and should inform faculty in their efforts to nurture and develop students' abilities and dispositions toward critical thinking. Teachers would benefit from further professional development focused on curricular alignment with critical thinking skills and dispositions and the assessments which measure their change. In Chapter Three there is a detailed discussion of the curricular intervention of this study, including a description of critical thinking skills and dispositions infused into the curriculum. Appendix C provides descriptions of classroom activities categorized by specific critical thinking skill skills. Past efforts to investigate the effects of specific teaching techniques may have encountered difficulty in attaining direct indicators of change (Tsui, 2002); however, a review of the findings of this study may provide the faculty with insights into possible improvements in the existing curriculum and pedagogy, and the means with which to evaluate it.

Although writing is an important aspect of the curricular program at the school whose archival data was used in this study, it was not examined as part of this research. Prior research has supported the relationships between critical thinking skills and writing skills (White, 2009; Daemplfe, 2002; Quitadamo & Kurtz, 2007), indicating positive and significant improvements in critical thinking skills as a result of infusion of critical thinking skills and writing strategies into the curriculum. The use of prompts and rubrics to develop and assess critical thinking skills, to recognize biases and examine divergent viewpoints has been promoted in prior research (Wolcott and Lynch, 1997), could be supported in practice in an inquiry based curricular program, and could lead to significant improvements in critical thinking as the result of the writing strategies promoted by the rubrics.

The math and science curricula in this program are living documents, with the faculty involved in ongoing changes throughout the academic year. Content, lab work, and writing assignments may be changed based on factors including measured student success, comprehension, and ability to apply across the curriculum being taught. It would benefit the faculty to examine the extent to which designed activities provide evidence of student critical thinking skills identified in this study.

Although this study focused on the extent to which student participation in an inquiry-based curricular treatment contributes to a change in disposition toward critical thinking and critical thinking skills, activities designed to support teachers in their efforts to implement new strategies related to these questions present an important consideration for practice. Teachers can benefit from inquiry experiences grounded in the same pedagogical principles they are expected to implement with their own students; debriefing sessions in which teachers view lessons taught by peers and provide feedback to one another, and reflections by an individual teacher on his or her own practice can be enhanced by another's observations and perceptions. Although this happens to some extent among the faculty of the school whose archival data was used in this study, a more structured format could be useful. It is important for future practice to develop assessment tools to determine more specifically what aspects of this curriculum and pedagogy are successful, and how to foster continued professional and individual growth.

Recommendations for Future Research

This study sought to establish the importance of student participation in an inquiry-based curricular treatment as a vehicle for change in disposition toward critical thinking and critical thinking skills. Students must be able to think critically in order to be prepared to compete for employment in a global economy, and the work towards this goal must begin as early as possible in the educational process.

As discussed in the literature review, there are examples at the K-12 level of the use of inquiry pedagogy in mathematics and science curriculum as a means to increase student critical thinking skills and dispositions; however, much of the prior research concerning critical thinking skills and dispositions has been conducted at the undergraduate and graduate levels, with a limited number of longitudinal studies.

In order to add to the body of research available to guide future educators and researchers, the author offers the following suggestions for future research.

The inclusion of the teaching of critical thinking skills in the curriculum can begin successfully at the primary grade levels (Bailin et al., 1999). The APA Delphi Report recommends that "from early childhood, people should be taught…to reason, to seek relevant facts, to consider options, and to understand the views of others" (Facione, 1990). The report also maintains that critical thinking skills and dispositions should be an integral part of K-12 curriculum at all levels.

There is a need, therefore, for more research at the K-12 level which includes studies to determine the extent to which student participation in an inquiry-based curricular treatment contributes to a change in disposition toward critical thinking and critical thinking skills. This research should address consideration of critical thinking skills and dispositions in the development of curriculum and pedagogy, assessment of critical thinking skills and dispositions independently and as part of a curriculum, and longitudinal studies to examine student growth between entry and exit points in K-12 education.

While prior research on critical thinking indicates that behavioral dispositions do not change in the short term (Giancarlo and Facione, 2001), the same researchers also found in a longitudinal study that undergraduate critical thinking disposition toward critical thinking changed significantly after two years. Giancarlo and Facione (2001) found that student tendency to seek truth and confidence in thinking critically changed significantly during their junior and senior years. Additional studies are needed to confirm these results which suggest that change is measured in years, not weeks.

In contrast, prior research indicates that critical thinking skills can be measurably changed in periods as short as six weeks (Quitadamo, Brahler, & Crouch, 2009). While their study reported some evidence of measurable change in undergraduate critical thinking skills within an academic semester, it was unclear as to whether the change was a function of intervention of chronological time or curricular intervention.

There is limited research about the development of critical thinking skills and dispositions over time (Lai, 2011). The American Philosophical Association (APA) cautions that its framework for critical thinking should not be interpreted as implying developmental progression or hierarchical taxonomy (Facione, 1990). Several empirical studies which have investigated the evolution of critical thinking skills of college students have found that the critical thinking scores of third year university students were significantly higher than the corresponding scores of first-year students (O'Hare and McGuinness, 2009).

Administering the CCTST and the CCTDI to students who were the sample for the current study three years after the post-test in this study would provide data in the change in critical thinking skills and dispositions at a time close to the expected graduation from high school. At that point in time, this group of students will have completed two additional years of the inquiry-based math and science curriculum, as well as two years of a science research course which requires them to design and execute a research project of their own design.

Writing has also been identified in the research as a means to improve critical thinking. In a study comparing critical thinking performance of students who experienced a laboratory writing treatment with those who experienced a traditional quiz-based laboratory, the writing group significantly improved critical thinking skills while the non-writing group did not (Quitadamo & Kurtz, 2007). Specifically, analysis and inference skills increased significantly in the writing group while the not-writing group did not.

While this study was limited to quantitative data and analysis, studies which combine quantitative and qualitative data and analysis would be recommended. Data collection and analysis could include review of student writing including lab reports and experimental design papers, student journals, student interviews, and observation of classroom instruction.

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APPENDIX A

APPENDIX A

CCTST *Scale Descriptions*

Reasoning Skills - Overall: The Reasoning Skills Overall describes overall strength in using reasoning to form reflective judgments about what to believe or what to do. To score well overall, the test-taker must excel in the sustained, focused and integrated application of core reasoning skills including analysis, interpretation, inference, evaluation, explanation, induction and deduction. The Overall score predicts the capacity for success in educational or workplace settings which demand reasoned decision making and thoughtful problem solving.

Analysis: Analytical reasoning skills enable people to identify assumptions, reasons and claims, and to examine how they interact in the formation of arguments. We use analysis to gather information from charts, graphs, diagrams, spoken language and documents. People with strong analytical skills attend to patterns and to details. They identify the elements of a situation and determine how those parts interact. Strong interpretation skills can support high quality analysis by providing insights into the significance of what a person is saying or what something means.

Inference: Inference skills enable us to draw conclusions from reasons and evidence. We use inference when we offer thoughtful suggestions and hypotheses. Inference skills indicate the necessary or the very probable consequences of a given set of facts and conditions. Conclusions, hypotheses, recommendations or decisions that are based on faulty analyses, misinformation, bad data or biased evaluations can turn out to be mistaken, even if they have been reached using excellent inference skills.

Evaluation: Evaluative reasoning skills enable us to assess the credibility of sources of information and the claims they make. And, we use these skills to determine the strength or weakness of arguments. Applying evaluation skills we can judge the quality of analyses, interpretations, explanations, inferences, options, opinions, beliefs, ideas, proposals, and decisions. Strong explanation skills can support high quality evaluation by providing the evidence, reasons, methods, criteria, or assumptions behind the claims made and the conclusions reached.

Deduction: Decision making in precisely defined contexts where rules, operating conditions, core beliefs, values, policies, principles, procedures and terminology completely determine the outcome depends on strong deductive reasoning skills. Deductive reasoning moves with exacting precision from the assumed truth of a set of beliefs to a conclusion which cannot be false if those beliefs are true. Deductive validity is rigorously logical and clear-cut. Deductive validity leaves no room for uncertainty, unless one alters the meanings of words or the grammar of the language.

Induction: Decision making in contexts of uncertainty relies on inductive reasoning. We use inductive reasoning skills when we draw inferences about what we think is probably true based on analogies, case studies, prior experience, statistical analyses, simulations, hypotheticals, and patterns recognized in familiar objects, events, experiences and behaviors. As long as there is the possibility, however remote, that a highly probable conclusion might be mistaken even though the evidence at hand is unchanged, the reasoning is inductive. Although it does not yield certainty, inductive reasoning can provide a confident basis for sold belief in our conclusions and a reasonable basis for action.

Interpretation: Interpretative skills are used to determine the precise meaning and significance of a message or signal, whether it is a gesture, sign, set of data, written or spoken words, diagram, icon, chart or graph. Correct interpretation depends on understanding the message in its context and in terms of who sent it, and for what purpose. Interpretation includes clarifying what something or someone means, grouping or categorizing information, and determining the significance of a message.

Explanation: Explanatory reasoning skills, when exercised prior to making a final decision about what to believe or what to do, enable us to describe the evidence, reasons, methods, assumptions, standards or rationale for those decisions, opinions, beliefs and conclusions. Strong explanatory skills enable people to discover, to test and to articulate the reasons for beliefs, events, actions and decisions.

APPENDIX B

APPENDIX B

CCTDI Scale Descriptions

Truth-seeking: Truth-seeking is the habit of always desiring the best possible understanding of any given situation; it is following reasons and evidence where ever they may lead, even if they lead one to question cherished beliefs. Truth-seekers ask hard, sometimes even frightening questions; they do not ignore relevant details; they strive not to let bias or preconception color their search for knowledge and truth. The opposite of truth-seeking is bias which ignores good reasons and relevant evidence in order not to have to face difficult ideas.

Open-mindedness: Open-mindedness is the tendency to allow others to voice views with which one may not agree. Open-minded people act with tolerance toward the opinions of others, knowing that often we all hold beliefs which make sense only from our own perspectives. Open-mindedness, as used here, is important for harmony in a pluralistic and complex society where people approach issues from different religious, political, social, family, cultural, and personal backgrounds. The opposite of open-mindedness is intolerance.

Analyticity: Analyticity is the tendency to be alert to what happens next. This is the habit of striving to anticipate both the good and the bad potential consequences or outcomes of situations, choices, proposals, and plans. The opposite of analyticity is being heedless of consequences, not attending to what happens next when one makes choices or accepts ideas uncritically.

Systematicity: Systematicity is the tendency or habit of striving to approach problems in a disciplined, orderly, and systematic way. The habit of being disorganized is the opposite tendency. The person who is strong in systematicity may not know of a given approach, or may not be skilled at using a given strategy of problem solving, but that person has the desire and tendency to try to approach questions and issues in an organized and orderly way.

Confidence in Reasoning: Confidence in reasoning is the habitual tendency to trust reflective thinking to solve problems and to make decisions. As with the other attributes measured here, confidence in reasoning applies to individuals and to groups. A family, team, office, community, or society can be trustful of reasoned judgment as the means of solving problems and reaching goals. The opposite habit is mistrust of reasoning, often manifested as aversion to the use of careful reason and reflection when making decisions or deciding what to believe or do.

Inquisitiveness: Inquisitiveness is intellectual curiosity. It is the tendency to want to know things, even if they are not immediately or obviously useful. It is being curious and eager to acquire new knowledge and to learn the explanations for things even when the applications of that new learning are not immediately apparent. The opposite of inquisitiveness is indifference.

Maturity of Judgment: Maturity of judgment is the habit of seeing the complexity of issues and yet striving to make timely decisions. A person with maturity of judgment understands that multiple solutions may be acceptable while yet appreciating the need to reach closure at times even in the absence of complete knowledge. The opposite, cognitive immaturity, is imprudent, black-and-white thinking, failing to make timely decisions, stubbornly refusing to change when reasons and evidence would indicate one is mistaken, or revising opinions willy-nilly without good reason for doing so.

APPENDIX C

APPENDIX C

Curricular Examples of Critical Thinking Skills

Critical Thinking Skill	**Classroom Activity Descriptions and Examples**
Analysis	*Students use analysis skills to gather information form charts, graphs, diagrams, spoken language and documents, attending to patterns, details, and elements of particular situations. The use of analytical reasoning skills in the development and execution of lab work enables students to identify assumptions, reasons and claims while examining how they interact in the formation of arguments.*
	Week 2: Distance versus displacement: Students design a lab to show if uniform motion is possible with ticker tape timers and carts; students gather, organize, and analyze data using charts, graphs and spreadsheets. Week 16: Circular motion: What holds a planet in motion? The teacher serves as an inquiry guide leading the students through a discussion in which they will identify what they need to know and how they will derive the answers to those questions. Students develop steps to actually "swing" a planet and record data, patterns, and observations of motion. Students organize data in a table then analyze first in their individual lab groups and then as an entire class. Students design and execute the lab, determine how to record the data, then analyze the data.
Inference	*Students use inference skills to draw conclusions from reasons and evidence, and to offer hypotheses.*
	Week 1: Pendulum Inquiry Lab: Students explore and discover the factors that affect the period of a simple pendulum using the steps of the scientific method discussed in the precious class. Students work in groups, design and perform the experiments, and analyze the data within the group. They share the data with other groups and perform class level analyses. Week 3: Constant Velocity Inquiry Lab: Students are involved in a Socratic seminar on the possibility of an object's traveling at constant speed and how one can measure whether they really do. This leads to the students proposing different hypotheses and experimental designs to verify their hypotheses. The students collect data, share data, and analyze the data to arrive at their conclusions. All of this is presented by each student in a formal lab report. This provides the opportunity for the students to ponder about why the velocity might change, how such changes may be described, and what may cause such changes.

Critical Thinking Skill	**Classroom Activity Descriptions and Examples**
Evaluation	*Students use evaluation skills to assess the credibility of sources of information and the claims that they make.*
	Repetitive throughout the course: Students produce written lab reports for each inquiry lab. Early lab reports are reviewed by teacher and feedback is provided prior to official grading so that students will develop good habits. Class discussions focuses on identifying and evaluating the criteria for what constitutes a credible source of information when substantiating observations in lab write-ups. Statements drawn from the text must be cited.
Deductive Reasoning	*Students use deductive reasoning skills to make decisions where rules, operating conditions, core beliefs, values, procedures and terminology can determine outcomes in the context of the development and execution of lab work.*
	Week 3: Socratic discussions and inquiry worksheets enable the students to develop an understanding of positive and negative acceleration, speed versus time, and uniform acceleration. With a foundation in these rules/operating conditions/terminology, students are prepared to execute several inquiry labs in this area. Week 27-28: Gas laws: Faculty develops a series of directed lab activities which are utilized to develop foundational knowledge in this area. These labs are followed by several inquiry labs in which students synthesize observations in a write-up intended to enable them to see relationships inherent in gas laws. Teachers work with the students to enable them to evidence a strong conceptual understanding of the material while at the same time leading students through discussion and directed inquiry that led to new knowledge and understanding. Classes covering the gas laws and work/energy require students to develop an understanding of specific formulas as well as an ability to apply those formulas. Teachers lead students through conversations to develop an understanding of abstract concepts and discrepant scientific events, followed by applications of the resulting formulas.

Critical Thinking Skills	**Classroom Activity Descriptions and Examples**
Inductive Reasoning	*Students use interpretative skills to determine the precise meaning and significance of sets of data, charts, and spoken words.*
	Week 28: Climate and factors controlling climate. Students use a spreadsheet program lesson to produce precipitation data for a chosen location. Students used this spreadsheet program in a previous lesson for a similar purpose. Students identify, defend and apply appropriate statistics for this data. Discussion of statistics that are commonly used as well as those that might be inappropriate. In subsequent lesson, students identify and replicate fifteen years of data. Using histograms they examine and discuss variability that is natural. Students work on developing monthly data analyses, observe patterns, draw hypotheticals, and draw on experiences in previous labs. Week 23: Work and energy. Students begin the class by developing an inquiry lab that investigates the conversion of energy, the relationship between force and stretch, and the energy of a spring. The development of the lab activity by the students allows them to work in small learning communities and consider alternate modes of investigation and problem solving. At the conclusion of the lab activity the data are discussed in class, and students record the data and analysis in their lab notebooks. This lab was designed to enable students to connect the concepts of work and energy to previous study of kinematics and dynamics earlier in the school year. A similar process of connections were observed in the classes and lab activities observed focusing on wave behavior and the connections to previous classes on laws of refraction.
Interpretive Skills	*Students use interpretative skills to determine the precise meaning and significance of sets of data, charts, and spoken words.*
	Week 13: Glaciers and Ice Core Data: Week 28: Weather and climate: Students learn statistical analysis (simple and conditional probabilities and discerning between the appropriate situations to do each); students then create a flow chart for weather-based statistical persistence. They use this process and the resulting document to interpret the data.

Critical Thinking Skills	**Classroom Activity Descriptions and Examples**
Explanatory Skills	*Students use explanatory reasoning skills to make final decisions about what to believe or what to do in a particular circumstance or experiment. The ability to explain the evidence, reasons, methods, or rationale for decisions and conclusions enables students to discover, test and articulate the reasons for beliefs and decisions.*
	During every inquiry lab the students collect data, share data, and analyze the data to arrive at their conclusions. All of this is presented by each student in a formal lab report. This provides the opportunity for the students to ponder about why the velocity might change, how such changes may be described, and what may cause such changes. Discussions take place in small lab groups followed by discussions among the entire class. In these discussions students are expected to present data, analysis and conclusions in a concise, articulate manner. They are mentored to learn how to respond to questions/suggestions from their classmates/colleagues during the course of discussions and presentations, and to articulate their reasons for beliefs and decisions.

APPENDIX D

UNIVERSITY of VIRGINIA
OFFICE OF THE VICE PRESIDENT FOR RESEARCH
INSTITUTIONAL REVIEW BOARD FOR THE SOCIAL AND BEHAVIORAL SCIENCES

In reply, please refer to: Project # 2015-0229-00

June 3, 2015

Jayne Fonash and Dennise Berry
Leadership, Foundations & Policy
47525 Compton Circle
Potomac Falls, VA 20165

Dear Jayne Fonash and Dennise Berry:

Thank you for submitting your project entitled: "Effects of an inquiry-based curricular program on aspects of critical thinking skills and dispositions" for review by the Institutional Review Board for the Social & Behavioral Sciences. The Board reviewed your Protocol on June 3, 2015.

The first action that the Board takes with a new project is to decide whether the project is exempt from a more detailed review by the Board because the project may fall into one of the categories of research described as "exempt" in the Code of Federal Regulations. Since the Board, and not individual researchers, is authorized to classify a project as exempt, we requested that you submit the materials describing your project so that we could make this initial decision.

As a result of this request, we have reviewed your project and classified it as exempt from further review by the Board for a period of four years. This means that you may conduct the study as planned and you are not required to submit requests for continuation until the end of the fourth year.

This project # 2015-0229-00 has been exempted for the period June 3, 2015 to June 2, 2019. If the study continues beyond the approval period, you will need to submit a continuation request to the Board. If you make changes in the study, you will need to notify the Board of the changes.

Sincerely,

Tonya R. Moon, Ph.D.
Chair, Institutional Review Board for the Social and Behavioral Sciences

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APPENDIX E

Loudoun County Public Schools
Department of Instruction
Research Office
21000 Education Court
Ashburn, Virginia 20148
Telephone: 571-252-1310
FAX: 571-252-1633

TO: Jayne Fonash

FROM: Ryan L. Tyler, Ph.D., Director of Research RT
Terri L. Breeden, Ed.D., Assistant Superintendent for Instruction TB

RE: Research Request

Date: June 29, 2015

Your request to conduct the study, Effects of an Inquiry-based Curricular Program on Aspects of Critical Thinking Skills and Dispositions, has been approved.

As a courtesy to Loudoun County Public Schools and the participants in your research, please provide a copy of your study and subsequent findings to the Research Office.

Contact Dr. Ryan Tyler, Director of Research, if you have any questions about the approval.

Good luck with your project.

Cc: Odette Scovel
Nereida Gonzalez-Sales
George Wolfe