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EFFECTS OF AN INQUIRY-BASED SCIENCE PROGRAM ON CRITICAL THINKING, SCIENCE PROCESS SKILLS, CREATIVITY, AND SCIENCE FAIR ACHIEVEMENT OF MIDDLE SCHOOL STUDENTS

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EFFECTS OF AN INQUIRY-BASED SCIENCE PROGRAM ON CRITICAL THINKING, SCIENCE PROCESS SKILLS, CREATIVITY, AND SCIENCE FAIR ACHIEVEMENT OF MIDDLE SCHOOL STUDENTS

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BS Biology, Iona College, 2000
MS Biology, Southern Connecticut State University, 2003

A Dissertation

Submitted in Partial Fulfillment of the

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EFFECTS OF AN INQUIRY-BASED SCIENCE PROGRAM ON CRITICAL THINKING, SCIENCE PROCESS SKILLS, CREATIVITY, AND SCIENCE FAIR ACHIEVEMENT OF MIDDLE SCHOOL STUDENTS

Christopher M. Longo, EdD

Western Connecticut State University

Abstract

This study investigated the impact of an inquiry-based science program on the critical thinking skills, science process skills, creativity, and science fair achievement of middle school students. Although research indicates the connection between inquiry and achievement, there is limited empirical research relating specific inquiry-based programs to critical thinking, creativity, and science fair achievement in middle school classrooms.

The research took place in a small, suburban middle school in the northeast from November 2010 to May 2011. A sample of convenience was comprised of seventh and eighth grade students. The study was quasi-experimental in nature, with a pretest-posttest comparison group design using intact classrooms of students. Five instruments were administered related to the elements of science process skills, critical thinking, creative thinking, and science fair achievement.

The scores of those students in the inquiry-based science program were compared to those students in the traditional science classroom to determine the impact of each method of delivering instruction. In the multivariate analysis of variance, the inquiry instruction group

scored significantly higher for science process skills as measured by the *Earthworm Test* ($p <$ .001) and Cognitive Integrity, an area of critical thinking measured by the *CM3* ($p < .025$).

In multiple regression analysis, program type contributed significantly to the prediction of science fair achievement scores above and beyond the predictor variables of science process skills, critical thinking, and creativity ($p < .001$). Science fair scores were significantly higher ($p < .001$) for the treatment as compared to that of the direct instruction group. Overall, science process skills ($p < .025$) and program type ($p < .001$) contributed significantly to the prediction of science fair achievement.

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2012

APPROVAL PAGE

WESTERN CONNECTICUT STATE UNIVERSITY

School of Professional Studies
Department of Education and Educational Psychology
Doctor of Education in Instructional Leadership

Doctor of Education Dissertation

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Presented by

Christopher M. Longo, EdD

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2012

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DEDICATION

I dedicate this accomplishment to my son, Andrew Daniel. You are the greatest thing to come into my life. You are the most curious boy that I have ever met, and it is fitting that I conducted a research study on inquiry and creativity. You amaze me each and every day. My goal as a father is to raise you to be successful, confident, and motivated, taking on any challenges that you may seek without any reservation to accomplish the impossible.

I also dedicate this achievement to the late Maddalena Jamele, my grandmother, who assisted in raising me and provided undying support in all areas of my life. Her advice, encouragement, and wisdom will always resonate in my hopes, dreams, and aspirations.

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CHAPTER ONE: INTRODUCTION AND IDENTIFICATION OF THE TOPIC

Inquiry learning "involves a flexible yet systematic approach toward solutions. Inquiry learning is learning about the topic being investigated while simultaneously learning about the process of inquiry" (Schön, 1992, p. 181). Manconi, Aulls, & Shore (2008) state that the inquiry process "is driven by the student's own curiosity, wonder, interest, or passion to understand an observation or solve a problem" (p. 249). The skills of inquiry require creative thinking that lead to the production of creative and authentic products (Renzulli, 2000). Although inquiry learning is a valued strategy for educational reform, it is not being effectively implemented in today's classrooms (Deters, 2004; Sampson, 2004).

The pressure of educators to meet the demands of legislation and standardized testing, while still delivering the necessary concepts by the academic year's end, narrows the focus of the curriculum and inhibits the creative process (Azzam, 2009). By contrast, constructivist perspectives uphold that learning is most effective when individuals pose and respond to questions across a range of complexity (Dewey, 1938).

Most researchers agree that there is a hierarchy of inquiry activities ranging from teacher-directed to student-directed (Bell, Smetana, & Binns, 2005; Colburn, 2000; Dunkhase, 2003; Herron, 1971; Martin-Hansen, 2002; Schwab, 1962). Inquiry activities can be divided into various levels based on the type of activity presented and the response expected from the learner. These activities fall along a continuum, beginning with the presentation of a structured inquiry process that the learner follows, and ultimately using a student-centered model where students design the questions to be investigated in an open-inquiry approach. Teachers might find it necessary to begin the process by providing a prompt, and then allowing students to investigate (guided inquiry). The guided inquiry approach provides the most flexibility for teachers to utilize an inquiry framework.

Although inquiry-based strategies are used across the curriculum (Shore, Aulls, & Delcourt, 2008), most reported applications of this type of learning relate to science instruction (Delcourt & McKinnon, 2011). Research indicates that an inquiry model plays a significant role in developing students' critical thinking skills (Alshraideh, 2009). Furthermore, inquiry instruction promotes positive classroom attitudes toward science and task orientation and results in knowledge gains compared to traditional science instruction (Bryant, 2006; Wolf & Fraser, 2008).

According to the National Science Education Standards, the National Research Council (NRC) defines inquiry as "the diverse ways that scientists study the natural world and as the activities used by students to formulate an understanding of the work that scientists do" (1996, p. 23). Sanderson (1971) described basic science process skills, such as making observations, inferring, measuring, communicating, and classifying, and integrated process skills to reflect the ability to control variables, formulate hypotheses, and interpret data. Nadelson (2009) states:

> Implementing inquiry curricula and instruction in which students learn and engage in guided research assignments that are detailed, scaffolded and supported, will increase the chance of successfully acquiring the targeted knowledge while preparing them to be increasingly independent learners. (p. 53)

Developing students' problem-solving and science process skills using real-world situations is equally as important as expanding their critical thinking with respect to inquiry.

Additionally, Krajcik, Blumenfeld, Marx, Bass, Fredricks & Soloway (1998) found that project-based science is one promising way to promote student inquiry skills.

It is the purpose of national and state science fair organizations to provide a forum to display these acquired skills. An important objective of the Connecticut Science Fair (CSF) is to attract young people to careers in science while developing skills essential to critical thinking (CSF, 2006). Shore, Delcourt, Syer and Shapiro (2008) state that the purpose of a science fair is to permit students to learn by doing. "The benefits of engaging students in investigation to answer authentic questions are substantial and include more thoughtful and robust science learning" (NRC, 1996, p. 31).

Furthermore, science fair projects that display high achievement are results of the creative process. This type of creative productivity can be nurtured in adolescents (Delcourt, 1993) as they develop original materials and products that are purposely designed to have an impact on target audiences (Renzulli, 1986).

Rationale for Selecting the Topic

The purpose of this study was to understand the impact of an inquiry-based science program on creative and critical thinking as well as to clarify the types of science process skills linked to student involvement in scientific experimentation. In addition, the ultimate goal was to investigate changes in the quality of science fair projects by implementing problem-finding and creative problem-solving strategies in science classes. This project aligns with the revisions in state science standards over the past five years. Not only do the new standards include requirements for developing inquiry skills, they provide a recommendation that science educators supplement or replace their teaching and learning techniques with inquiry-related strategies.

In the spring of 2010, the researcher conducted an informal assessment as part of a program evaluation to determine the need for inquiry in a particular middle school. In this causal comparative pilot study, the researcher found that scores on a critical thinking index were higher for students who experienced inquiry as opposed to students who were in a traditional setting in their science classes. Therefore, the present study was conducted to investigate whether or not using an inquiry program rooted in critical and creative thinking could result in significantly higher science process skills scores and produce higher quality science fair projects for students who participated in the inquiry program as compared to those who followed a direct instruction model. These types of advanced projects are those that contain original ideas based on thorough research and brainstorming.

Critical thinking and science process skills are complex and not easily addressed by traditional means of instruction. By providing an environment where students incorporate strategies to solve real-world problems and produce creative ideas and products, there is a better chance that critical thinking can be stimulated. This research study examined the effects of an inquiry program that included specific models for both critical thinking skills and creative problem-solving with the goal of expanding the number of ideas students developed for science fair projects and ultimately improving their science fair achievement.

Statement of the Problem

Due to the needs of state testing, there is a focus on accountability for teachers to enhance student achievement. Educators must determine what strategies can effectively address this issue. While many studies exist that investigate the positive effect of inquiry-based learning on student achievement (Chang & Mao, 1999; Geier, Blumenfeld & Marx, 2008; Wolf & Fraser, 2008), there is limited research about the effects of this type of program on the process associated with students' science fair projects (LaBanca, 2008).

Potential Benefits of the Research

This quantitative research study addresses the necessity for an inquiry-based science program at the middle school level. It is used to investigate the program's impact on students who participated in the program and the manner in which the program features affect the quality of these projects. Results of this research could assist educators to not only develop instruction that stimulates students to brainstorm effectively, think critically, and formulate ideas creatively, but develop the science process skills needed to understand how to conduct scientific investigations that produce more authentic and meaningful outcomes.

The inquiry initiative underlying this research was based on the National and Connecticut Science Frameworks (CSDE, 2004; NRC, 1996). Most of these standards are directly linked to inquiry, as well as the science fair process. This research serves to investigate the relationship between an inquiry learning model and the development of science fair projects.

With an inquiry learning approach, students can explore areas in science by asking questions, forming hypotheses, and discovering knowledge using limited assistance. As Hammerman (2006) indicated, "Asking theoretical questions, making observations, developing hypotheses, engaging in experimentation, collecting and analyzing data, drawing conclusions, making inferences, and formulating new questions are some of the exciting processes that are practiced through inquiry-based science" (p. xxii). To establish these skills, students should be encouraged to think like scientists and make real-world connections, two powerful goals for inquiry learning in the classroom.

Definition of Key Terms

The following terms will be used throughout this research study:

1. **Brainstorming** is "the encouragement of a free-flowing stream of ideas, while temporarily withholding all criticism or judgment" (Treffinger & Isaksen, 1985, p. 4).
2. **Creative Problem-solving (CPS)** is an established six-step method for teaching critical thinking skills and metacognitive strategies. The steps are: (a) mess-finding, (b) data-finding, (c) problem-finding, (d) idea-finding, (e) solution-finding, and (f) acceptance-finding (Treffinger & Isaksen, 2005).
3. **Creative thinking** is described as "the process of sensing difficulties, problems, gaps in information, or missing elements; making guesses or formulating hypotheses about these deficiencies; testing these guesses and possibly revising and retesting them; and finally communicating the results" (Torrance, 1995, p. 75).
4. **Critical thinking** is "purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as an explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based" (Facione, 1990, p. 2).
5. **A direct instruction model** is based on the work of Madeline Hunter (1984), who describes seven steps in the process: "(a) presentation of an anticipatory set, which causes the learners to focus on learning; (b) a description of objectives and purpose, in which the teacher makes clear what is to be learned; (c) an input stage, in which a new knowledge, process, or skill is presented to the students;

(d) modeling, in which the new learning is demonstrated; (e) checking for understanding; (f) guided practice under the careful supervision of the teacher; (g) independent practice that encourages learners to perform or utilize the new learning on their own" (Gunter, Estes, & Schwab, 2003, p. 64).

6. **Inquiry** is a process "driven by the student's own curiosity, wonder, interest, or passion to understand an observation or solve a problem" (Manconi, Aulls, & Shore, 2008, p. 249). Inquiry includes "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council, 1996, p. 23).
7. **Problem-solving** is an approach where learners "recognize patterns that they have experienced before matching these patterns to corresponding aspects of the problem at hand" (Margolis, 1987, p. 60).
8. **A science fair** is "an exhibition of students' scientific experiments or investigations that they completed over the course of the school year" (Shore, Delcourt, Syer & Shapiro, 2008, p. 93). Science fairs are typically held in the spring of the academic year.
9. **Science process skills** are referred to as an "understanding of methods and procedures of scientific investigation" (Bilgin, 2006, p. 27).
10. **The Suchman Inquiry Model** is an instructional model that includes the following steps: "(a) select a problem and conduct research; (b) introduce the process and present the problem; (c) gather data; (d) develop a theory and verify; (e) explain the theory and state the rules associated with it; (f) analyze the process; and (g) evaluate" (Gunter, Estes, & Schwab, 2003, p. 118).

Methodology Overview

The purpose of this study was twofold: to examine the effect of participation in an inquiry-based science program, on the critical thinking, creative thinking, and science process skills of middle school students and to investigate the degree to which science process skills, critical thinking, creativity, and participation in a science inquiry program predicted science fair achievement.

Research Questions

This research addressed the following questions:

1. Is there a significant difference in critical thinking skills, science process skills and creativity of middle school science students who participate in an inquiry-based program as compared to students who participate in a science program employing direct instruction?
2. To what extent and in what manner do critical thinking skills, science process skills, creativity, and program type predict science fair achievement?

Description of the Setting and the Subjects

This research took place in a middle school composed of sixth, seventh, and eighth grade students in a small, suburban community in the northeast of the United States. The school district has changed in terms of diversity over the past few years with a population of predominantly white that also includes Hispanic, black, and Asian students. The total population of this school was 690 students.

The study focused on students in Grade 7 and Grade 8. All science teachers in the seventh grade (n = 2) and eighth grade (n = 2) participated in the study. The seventh-grade curriculum focused on life science and the eighth grade included earth science. One teacher per grade level was randomly assigned to an inquiry program in science that was implemented over a 19-week period. Two teachers taught using direct instruction and two teachers taught through inquiry instruction. The study included all school days from late November until the week before spring break.

Each of these four teachers taught five science classes. All students from these classes were invited to participate in the study. Forty-three students in the seventh grade and 70 students in the eighth grade consented to participate in the inquiry instruction program and 68 seventh-grade students and 48 eighth-grade students participated in the direct instruction aspect of the study.

Description of the Inquiry and Direct Instruction Programs

Inquiry program. Teachers in the treatment group used components of the Creative Problem-solving (CPS) model (Treffinger & Isaksen, 2005), as well as the Suchman inquiry model (Suchman, 1968) in earth science and biology classes. Each time used, the treatment teachers monitored the students and collected their data and ideas. Strategies from the CPS model allowed for the brainstorming of science fair topic ideas. A combination of worksheets and inquiry journals shared at weekly teacher/researcher meetings served as evidence that these types of activities were taking place faithfully. Students practiced how to conduct experiments by implementing inquiry-based labs in their science classes. Student work collected from activities, along with reflections in inquiry journals, provided a focus for how students were progressing and provided evidence that teachers in the treatment group used the inquiry program strategies.

Direct instruction program. Likewise, the researcher confirmed the strategies used by teachers in the comparison group. Weekly discussions with teachers provided information for the researcher regarding instruction and progress related to daily lessons as well as the science fair process. Although students were involved in grade-level appropriate labs, and in the science fair process, it was clear from these meetings that the CPS and Suchman strategies used in the inquiry program were not being used in the classes of the comparison group.

Instrumentation

Data were collected using five instruments. The *California Measure of Mental Motivation* (*CM3*) was utilized to measure critical thinking (Giancarlo, 2010). The *Diet Cola Test* (*DCT*) (Fowler, 1990), and its alternate form, the *Earthworm Test* (Adams & Callahan, 1995), were used to measure science process skills. The *Connecticut Science Fair (CSF) Rubric* (CSF, 2006) was employed to measure various skills related to science fair achievement. The *Torrance Test of Creative Thinking* (*TTCT*), Figural Forms A & B (Torrance, 1966) were used to measure the elements of creative thinking. Furthermore, inquiry-based science labs and journals were conducted and used as a monitoring tool for verification of the progression of the treatment.

Description of the Research Design

The methodology used in this study was a quasi-experimental design in which a sample of convenience (n = 229) was studied to determine the impact of an inquiry-based science program on the critical thinking skills, science process skills, creativity, and science fair achievement of middle school students.

Description and Justification of the Analyses

The quantitative data collected related to research question 1 was analyzed using a multivariate analysis of variance (MANOVA) and research question 2 was examined through a multiple linear regression analysis (Meyers, Gamst, & Guarino, 2006).

Initial Limitations

There was no random assignment of students to the comparison and experimental groups. The researcher was unable to control for differences in class sizes, as intact groups were employed in this study. The study did not begin at the start of the school year. Therefore, it is possible that teachers implemented components of inquiry in their classes based on prior professional development and personal reading on instruction.

Chapter Summary

Chapter One affirms the importance of inquiry in science education. The purpose of this study was to implement an inquiry-based science program that not only influenced creative and critical thinking, but improved the quality of science fair projects. It was the goal of this type of program to increase science fair achievement and to move away from the generic science fair projects that lack creativity, in terms of fluency and originality of ideas. By implementing problem-finding and creative problem-solving strategies in science lessons, the goal of producing high quality science fair projects becomes a reality.

A middle school inquiry-based science program serves as a bridge to developing an interest and a sense of wonder for science. It is hoped that this research will assist educators in developing effective science instruction through an inquiry approach. This type of instruction stimulates students to brainstorm effectively, think critically, and develop science process skills needed to understand how to conduct scientific investigations that produce authentic and meaningful products.

CHAPTER TWO: REVIEW OF THE LITERATURE

To create a context for this study, the review of literature is divided into five sections: theoretical foundation, inquiry in science, creative thinking, critical thinking, and science projects. Inquiry's roots are in constructivism (Bruner, 1961; Dewey, 1938; Perkins, 1991). The inquiry approach has been defined similarly by various researchers who have focused on different levels along a continuum (Bell, Smetana, & Binns, 2005; Colburn, 2000; Dunkhase, 2003; Herron, 1971; Martin-Hansen, 2002; Schwab, 1962).

Inquiry as a process has transformed into a successful teaching strategy that has produced significant gains in achievement (Blanchard, Southerland, Osborne, Sampson, & Annetta, 2010; Chang & Mao, 1999; Mattheis & Nakayama, 1988; Panasan & Nuangchalerm, 2010; Randler & Bogner, 2002). Despite limited research about the constructs of critical and creative thinking in science at the middle school level, these areas still contribute to the open-ended nature of inquiry learning, specifically, designing authentic, high quality science fair projects.

Constructivist Theory of Learning

The theoretical basis for this study lies in a constructivist approach. The foundation of this theory is rooted in John Dewey's support of progressive education. Under this theory, new learning is built upon existing knowledge. Dewey (1938) explained that "there is an innate and necessary relation between the processes of actual experience and education" (p. 20). This theoretical underpinning provides a framework for the fundamentals associated with inquiry learning.

Dewey (1933) stated that inquiry is "An active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends" (p. 9). Dewey (1938) described traditional education as the "acquisition of what already is incorporated in books and is in the heads of the elders…taught as a finished product, with little regard either to the ways in which it was originally built up or to changes that will surely occur in the future" (p. 19). The experience of manipulating science content into meaningful instruction provides students with the ability to construct meaning rather than to merely repeat it. "Every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after" (Dewey, 1938, p. 35). This structure of the development of prior knowledge of thinking is the basis for learners to frame thoughts and expand on ideas.

In conjunction with Dewey's constructivist beliefs of constructing meaning rather than repeating content, Perkins (1991) believed that constructive processes allowed learners to form, elaborate, and test a candidate's mental structures until a satisfactory constructed thought emerges. Similarly, Bruner (1961) suggested that instruction must bring together the nature of knowledge, the nature of the knower, and the nature of the knowledge-getting process. Bringing together knowledge with process is the precursor to thinking critically. The knowledge-getting process promotes problem-solving, which requires critical thinking and the use of a scientific process (NRC, 1996). These ideas contribute to components of scientific inquiry, ranging across various instructional methods (Bell, Smetana, & Binns, 2005; Colburn, 2000; Dunkhase, 2003; Herron, 1971; Martin-Hansen, 2002; Schwab, 1962). These models are based on a constructivist approach, where ideas are scaffolded in order to problem solve (Bruner, 1977; Dewey, 1938).

The theory that supports inquiry learning provides a basis for measuring critical and creative thinking, processes that depend on the construction of meaning. The process skills used in inquiry classrooms are a result of these thought processes as students construct meaning from structured inquiry to open inquiry processes.

Perspectives on Inquiry

National and state departments of education include guided inquiry as a component of the science curriculum. The developed standards link to constructivist theory and provide a framework for teachers for what skills are utilized in inquiry. At the national level, the NRC (1996) encourages the use of inquiry by stating: “Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world” (p. 23). These aspects include the process skills related to scientific inquiry. The Connecticut State Department of Education (CSDE; 2004) lists scientific inquiry as part of the curriculum frameworks citing scientific inquiry as:

> …a thoughtful and coordinated attempt to search out, describe, explain and predict natural phenomena. Scientific inquiry progresses through a continuous process of questioning, data collection, analysis and interpretation. (p. 19)

In conjunction with national and state science frameworks, Beyer (1979) describes inquiry as the systematic manipulation of information to find answers to a question or a problem that are supported with evidence. “Inquiry is learning by questioning and investigation; the questions asked and means for investigation are vast, non-linear, and idiosyncratic” (Shore, Birlean, Walker, Ritchie, LaBanca, & Aulls, 2009, p. 141). Hawkins & Pea (1987) believe inquiry encompasses complex, higher-order skills that include creating a problem, collecting data to solve the problem, and making sense of that information. These views are consistent with the characteristics of the components of the inquiry process implemented in this study.

The process of inquiry is perpetual in that students develop their own process for solving a type of problem. Schön (1992) stated that inquiry is:

> …concerned with solving problems but it does not require solutions to problems. It involves a flexible yet systematic approach toward solutions. Inquiry learning is learning about the topic being investigated while simultaneously learning about the process of inquiry. (p. 181)

Windschitl (2008) described inquiry according to four interrelated areas: (a) organizing what we know, (b) generating a model, (c) seeking evidence, and (d) constructing an argument. These areas of focus serve as components of knowledge-building activities for problem-solving in science.

Inquiry is rooted in a constructivist approach, where students become self-directed learners when they progress from guided to open inquiry. Bruner (1961) stated, "I have never seen anybody improve in the art and technique of inquiry by any means other than engaging in inquiry" (p. 32). Bandura (1997) explained the manner in which individuals learn new behaviors through a process that involves observation, interaction, and modeling. When undertaking inquiry activities, students use skills such as making observations, inferences, and creating questions. In a guided inquiry approach, the teacher models in a way that provides structure for students as they begin to explore. In contrast, an open inquiry approach requires higher level thinking where students ask their own questions (LaBanca, 2008).

An inquiry continuum. The NRC (2000) described inquiry according to a continuum from less learner self-direction to more learner self-direction which relates to more teacher direction to less teacher direction. Regardless, direct instruction and inquiry instruction are both important strategies for use in middle schools. The amount of guidance and support that the teacher provides for students varies for each classroom, as the teacher differentiates for students of varying ability.

Inquiry-based instructional methods are often classified at the opposite end of the continuum as direct instruction models. Furtak (2006) states:

> The continuum is bordered on one side by traditional, direct instruction in which students are told the answers they are expected to learn by the teacher. At the other end of the continuum, students design and conduct their own investigations into phenomena that are not known to the teacher in what can be called open-ended scientific inquiry. (p. 454)

Current inquiry models reflect earlier research on guided inquiry. The many similarities and the few differences provide a perspective on today's science instruction. Schwab (1962) proposes inquiry according to questioning, methods and interpretation of results. Herron (1971) presented a continuum ranging from confirmation to open inquiry methods of instruction. Similarly, Colburn (2000) and Martin-Hansen (2002) described models that range from structured instruction to open inquiry instruction. Dunkhase (2003) developed a similar model of inquiry, with the addition of the coupled inquiry level, an instructional method that combines guided and open inquiry approaches. Most recently, Bell, Smetana, and Binns (2005) proposed a model that had similarities with all of the above models, with a close link to Herron's (1971) model.

Schwab's levels of inquiry. Schwab (1962) defined inquiry according to four levels. Each level in this classification scheme was related to three areas: source of the question, data collection methods, and interpretation of the results.

As the responsibility shifts from teacher to student, the levels increase from 0 to 3 respectively. At level 0, the question, data collection methods, and interpretation of results are all provided by the teacher. At level 1, the question and methods are provided for the learner, while the interpretation of results is open to the learner. In level 2 inquiry, only the question is provided for the students, while level 3 represents open-inquiry, where the question, methods, and results are constructed by the students. See Table 1 for a schematic of this model.

Table 1

Schwab's Levels of Inquiry

Inquiry level	Components		
	Source of Question	Methods	Interpretation of results
0	√*	√	√
1	√	√	
2	√		
3			

Note. Schwab (1962). *The √ indicates that the component of inquiry is provided by the teacher.

Herron's levels of inquiry. The Herron model is commonly referenced in many current inquiry models. In the first stage, students are presented with a prescribed activity, where they follow teacher directions to accomplish a task. The next phase is structured inquiry, in which the teacher presents the problem for students to solve. Next, in guided inquiry, the teacher presents the problem, but releases some of the responsibility of learning to the students as they craft their own procedures. Lastly, open inquiry invites students to investigate their own topic-related questions and design their own procedures. See Table 2 for a full description of the levels of inquiry according to Herron.

Table 2

Herron's Levels of Inquiry

	Level	Description
0	Confirmation/Verification	Students confirm a principle through a prescribed activity when the results are known in advance.
1	Structured Inquiry	Students investigate a teacher-presented question through a prescribed procedure.
2	Guided Inquiry	Students investigate a teacher-presented question using student designed/selected procedures.
3	Open Inquiry	Students investigate topic-related questions that are student formulated through student designed procedures.

Note. Herron (1971).

Colburn's view of inquiry. Colburn (2000) defined inquiry as "the creation of a classroom where students are engaged in essentially open-ended, student-centered, hands-on activities" (p. 33). Colburn classified inquiry according to four approaches: structured inquiry, guided inquiry, open inquiry, and learning cycle. These levels mirror the levels described earlier (Herron, 1971; Schwab, 1962).

*Structured inquiry***.** According to Colburn (2000), structured inquiry allows the teacher to provide a problem for students, along with the materials and procedures. The students investigate the problem and discover the relationship between variables. These types of activities are easy to follow and have predetermined outcomes.

*Guided inquiry***.** Guided inquiry allows students to design their own procedure and only the materials and the problem are provided (Colburn, 2000). The teacher helps students develop investigations in guided inquiry. The teacher usually chooses the question for students to investigate.

Open inquiry. Open inquiry is similar to guided inquiry except students formulate their own problem to investigate. Colburn (2000) defined open or full inquiry as "a student-centered approach that begins with a student's question, followed by the student or groups of students designing and conducting an investigation or experiment and communicating results" (p. 43).

Learning cycle. Colburn (2000) suggested another level of inquiry similar to guided inquiry which he termed learning cycle. Students investigate a new concept and follow guided inquiry procedures. After a discussion by the students and teacher, students then apply the concept in a different context.

Martin-Hansen's view of inquiry. Martin-Hansen (2002) concurred with the National Research Council's definition of inquiry: "the diverse ways that scientists study the natural world and as the activities used by students to formulate an understanding of the work that scientists do" (NRC, 1996, p. 23). Martin-Hansen (2002) classified inquiry into four levels similar to Colburn: structured inquiry, guided inquiry, coupled inquiry, and open inquiry.

Structured inquiry. This level consists of a teacher-directed method of instruction. "Typically, this results in a cookbook lesson in which students follow teacher directions to come up with a specific end product" (Martin-Hansen, 2002, p. 37). This method can be useful for support in some classrooms, however student engagement is limited.

Guided inquiry. In this method of instruction, the teacher chooses a question for students, and the students develop the plan to proceed in the investigation. "Teachers find that this is the time when specific skills needed for future open-inquiry investigations can be taught within context" (Martin-Hansen, 2002, p. 35). It is crucial for students to master guided inquiry before attempting full or open inquiry.

Coupled inquiry. Martin-Hansen (2002) viewed coupled inquiry as a combination of a guided inquiry approach with an open-ended approach. By beginning with the guided method, and then moving to a more student-centered approach, specific concepts are explored, allowing students to make connections. The process of coupled inquiry is based on the cycle proposed by Dunkhase (2000) and Martin (2001).

*Open inquiry***.** Martin-Hansen's (2002) description of open inquiry is the same as that of other researchers in that open inquiry is student-centered, where students design and conduct an investigation and communicate the results. There is also a common theme of open inquiry among researchers that this approach most closely mirrors the work of scientists.

Dunkhase's view of coupled inquiry. Coupled inquiry joins guided and open inquiry approaches (Dunkhase, 2003). As Martin-Hansen placed the couple inquiry strategy between the guided and open inquiry levels, Dunkhase defined coupled inquiry as a process that includes several steps. By assigning a problem for investigation, a guided approach is used first. Next, student-centered activities of an open-ended nature follow. Dunkhase (2003) described the coupled inquiry process according to the following steps: (a) invitation to inquiry, (b) teacher-initiated guided inquiry, (c) explore on your own, (d) student-initiated open inquiry, and (e) inquiry resolution. This process provides teachers with a balance of guided and open inquiry approaches to allow for successful differentiation.

Invitation to inquiry. The invitation to inquiry stage is the hook, used to stimulate student interest in the topic. This phase includes the creation of predictions based on prior knowledge. This stage provides a lead-in to guided inquiry instruction.

*Teacher-initiated guided inquiry levels***.** The guided inquiry stage allows teachers to direct students toward specific concepts and content standards. Even though the teacher is initially in control, this stage is still guided inquiry because the students conduct the investigation, interpret the results and make conclusions based on the data.

Explore on your own. Explore on your own, the third stage of this inquiry model, is the most important of the cycle. Dunkhase (2003) described the explore on your own stage as follows:

> This stage explicitly promotes the curiosity of the learners by encouraging them to personally explore the phenomena of interest. Here, the investigators are allowed to play around with the materials used in the guided investigation and most importantly, to generate their own questions that might be investigated in the next stage of the cycle – the open inquiry. (p. 13)

Open-inquiry. The open inquiry stage of Dunkhase's coupled inquiry model includes the discussion of the generated questions in the previous stage. These questions are selected based on negotiations of the students. The investigations are then designed, conducted and results are interpreted. Finally, the results are shared with audiences such as the teacher, the class, and community.

Inquiry resolution. In the inquiry resolution stage, the teacher reviews the student inquiry presentations for common understandings and discrepancies. This stage allows for closure and is an opportunity for re-teaching, validation, clarification, and enrichment. Additional content material is presented in the form of textbook reading or web searching.

Levels of inquiry according to Bell, Smetana, and Binns**.** This inquiry continuum is defined by the areas of questioning, methods, and the student solution. As a student experiences these different methods of instruction, less support is given by the teacher from the confirmation stage to the open inquiry stage, where the question, methods, and solution are not divulged to the student. See Table 3 for a chart that organizes the various levels of this type of inquiry continuum.

Table 3

Four Levels of Inquiry According to Bell, Smetana, and Binns

	Inquiry level	Components		
		Question	Methods	Solution
1	Confirmation	√*	√	√
2	Structured Inquiry	√	√	
3	Guided Inquiry	√		
4	Open Inquiry			

Note. Bell, Smetana, & Binns (2005). *The √ indicates that the component of inquiry is provided by the teacher.

Grady's inquiry matrix. Another continuum associated with inquiry was described by Grady (2010) as the Matrix for Assessing and Planning Scientific Inquiry (MAPSI). Grady (2010) defined four levels of this matrix as: (a) generating scientifically orientated questions, (b) making predictions or posing preliminary hypotheses, (c) designing or conducting the research study, and (d) explaining results. Each of the subcomponents of this model include target areas from least complex to most complex. The levels of inquiry increase from guided forms of inquiry, where instruction is scaffolded for students, to open inquiry, where students are given more responsibility in the learning.

Similarities and differences between inquiry levels. The levels of inquiry described by researchers have clear similarities. The term inquiry has been understood to encompass student-directed, hands-on activities that result in higher-level thinking. Also, there are commonalities in the nomenclature used to classify the levels. Although structured inquiry and guided inquiry are used simultaneously by the authors, others believe that there are slight differences in the processes in terms of how much of the responsibility of the learning is released to the students. All authors use the terms guided inquiry and open-inquiry. Table 4 defines the levels of inquiry used by some researchers. The table is devised to provide a comparison between the similarities and differences in typical inquiry processes.

Table 4

A Comparison of Four Types of Inquiry

Herron (1971)	Colburn (2000)	Dunkhase (2000)	Martin-Hansen (2002)
Confirmation			
Structured Inquiry	Structured Inquiry		Structured Inquiry
		Invitation to Inquiry	
Guided Inquiry	Guided Inquiry	Guided Inquiry	Guided Inquiry
			Coupled Inquiry
		Explore on Your Own	
Open Inquiry	Open Inquiry	Open Inquiry	Open Inquiry

A proposed inquiry model. The inquiry program used in this dissertation combines the qualities of both guided inquiry and open-inquiry. While students are provided with the question for investigation in some activities, other activities allow for the creation of ideas and investigations that are student-based. Teachers often use guided inquiry activities as ways to train students for open-inquiry.

Teachers in the treatment program employed a structured method of researching science fair project ideas through the use of creative problem-solving. Guided inquiry was evident through the use of laboratory activities, in which students developed their own procedures based on the topic. Open inquiry was utilized judiciously as students developed their own questions in various activities.

The Need for Middle School Inquiry Research

There is limited research in the area of middle school inquiry. In a recent EBSCO search (using these databases: Academic Search Premier, ERIC, Education Research Complete, and Teacher Reference Center), only 17 results were found when using the search term, "middle school science inquiry" over the last 10 years. When using search term, "middle school inquiry instruction," only seven results were found. In fact, when using generic search term "middle school inquiry," 58 results were retrieved from the past 10 years, with more than half of these references as informational journal articles or secondary resources. Therefore, this literature review was expanded to other academic levels, in the search for primary sources of literature.

Research Comparing Inquiry Instruction with Traditional Methods

Researchers who have investigated the use of inquiry methods have reported significant results for student achievement, which provides a foundation for this dissertation (Blanchard, Southerland, Osborne, Sampson, & Annetta, 2010; Chang & Mao, 1999; Mattheis & Nakayama, 1988; Panasan & Nuangchalerm, 2010; Randler & Bogner, 2002). These studied provide various viewpoints comparing inquiry instruction to the following direct instruction practices: lecture, textbook approach, slide presentation, and prescribed activities.

Inquiry research in elementary and secondary education. Research has been conducted to compare guided inquiry to an approach that uses the textbook as the focus. Mattheis and Nakayama (1988) conducted a quasi-experimental posttest only non-equivalent control group design in which they examined the effects of a laboratory-centered inquiry program on laboratory skills, science process skills, and understanding of science knowledge in middle grade students. The sample consisted of 85 sixth grade students and 141 seventh grade students. Those receiving the treatment ($n = 47$) were part of a guided inquiry program called *Foundational Approaches in Science Teaching* (FAST). The sixth grade non-inquiry group ($n = 38$) were taught through a traditional science textbook approach. Those in the seventh grade were also divided into a FAST group ($n = 83$) and a non-FAST group ($n = 58$). The treatment consisted of laboratory and field-centered activities, with 60%-80% of class time devoted to student investigations. This research spanned the length of the school year, and at the conclusion of the year, the following posttests were administered: Laboratory Skills Test (LST), Performance of Process Skills (POPS), an assessment of basic science knowledge, and the California Achievement Test (CAT).

A multivariate analysis of covariance (MANCOVA) was used to examine the effects of the treatment across the dependent variables. The CAT assessment was used as the covariate. The findings of this research demonstrated that this type of inquiry instruction can lead to improved achievement, laboratory skills, and science process skills in sixth grade students [$F(5, 78) = 5.53$, $p < .001$] and in seventh grade students [$F(5, 134) = 11.14$, $p < .001$.] The researchers also measured the effects of the FAST treatment on each of the dependent variables using a univariate analysis of covariance (ANCOVA) with CAT as the covariate. The results in sixth grade were significant for the FAST treatment for laboratory skills measured by the LST [$F(1, 82) = 19.05$, $p < .001$], process skills as measured by the POPS [$F(1, 82) = 8.44$, $p < .01$], and science knowledge as measured the researcher-developed assessment [$F(1, 82) = 4.58$, $p < .05$]. The FAST treatment also produced significant results in seventh grade in laboratory skills [$F(1, 138) = 43.29$, $p < .001$] and process skills [$F(1, 138) = 7.40$, $p < .01$].

It was concluded from this study that this type of lab-centered, guided inquiry program (FAST) improved students' ability in laboratory process skills, such as collecting and interpreting data. Limitations for this study cited by the researchers included: variations related to characteristics of the educational environment, prior teaching experience, and the use of materials in the classroom by each teacher.

Similar to the previous study, Chang & Mao (1999) investigated the impact of inquiry-group instruction and traditional teaching methods on student learning in earth science and student attitudes towards the subject. The researchers employed a quasi-experimental design with a sample of 612 ninth grade students, where students receiving the guided inquiry treatment (n = 319) experienced hands-on activities.

The treatment group worked in cooperative settings and completed presentations, whereas the control group learned through lecture and used a textbook. The inquiry group gathered, recorded, and interpreted data. The control group of students was provided with clear and detailed directions of what assignment to complete and where they could find the answers to the information presented.

The findings of this research demonstrated statistical significance in favor of the treatment group. Inquiry instruction led to higher scores for both student achievement, $F(1,13) = 7.41$, $p < .05$ and attitudes toward earth science $F(1, 13) = 7.50$, $p < .05$, as compared to direct instruction. Chang & Mao also concluded that "the inquiry-group approach encouraged students to work collaboratively in groups and therefore helped students to actively construct their own meaningful learning" (p. 344).

The researchers described a possible limitation to this study as variation due to cultural differences. This study took place in Taiwan, where students were noted as being quiet and passive learners. Despite this, the researchers concluded that the results could be generalized to the United States.

According to Change & Mao (1999), there is a clear indication that inquiry instruction benefits student achievement and science process skills. Randler & Bogner (2002) investigated whether inquiry-oriented instruction had a greater effect than traditional approaches on science achievement. This quasi-experimental pretest/posttest study examined fifth and sixth grade students (n = 240) of moderate to high ability. The treatment consisted of hands-on, cooperative field work with bird identification, whereas the control group was focused on a teacher-centered slide presentation of the same content. A total of three content-related, achievement tests were administered: one before instruction, one immediately after instruction, and a last assessment six weeks after instruction to assess the long-term effects of the treatment.

The findings of this study suggested that collaborative, hands-on inquiry instruction was more effective for high-ability students ($F = 6.20$, $p < .01$), whereas traditional methods were more effective for moderate ability students. The results suggested that cooperative and learner-centered environments assisted learners in obtaining knowledge and outdoor ecology should be supported by prior teaching in the classroom. Limitations cited by the researchers included the students' prior experience or lack of experience with hands-on activities. The researchers also stated that the application of the pretest might influence the level of achievement due to repeat testing.

From the studies described earlier, there are clear benefits from using inquiry-based instructional models. There is also a correlation between inquiry and project-based learning, in addition to gains in student achievement for inquiry instruction. Lab-based and hands-on activities have benefited student achievement. Panasan & Nuangchalerm (2010) conducted a quasi-experimental pretest/posttest study, measuring the effects of guided inquiry and project-based learning on achievement, analytical thinking, and science process skills assessments. The study was comprised of fifth grade science students in Thailand (n = 88). In this research, 44 students experienced project-based learning activities and 44 students experienced inquiry-based activities for one semester.

Although significant results were not found after analyzing all variables using a multivariate analysis of variance (MANOVA), findings suggested that learning achievement correlated with science process skills ($r = .390$, $p < .05$) and analytical thinking ($r = .614$, $p < .05$). Also, science process skills correlated with analytical thinking ($r = .476$, $p < .05$). The researchers concluded that by utilizing inquiry and project-based learning activities, positive correlations existed between learning achievement, science process skills and analytical thinking. Limitations for this study were not described by the researchers. This research resulted in the following conclusion: components of project-based learning can complement inquiry learning programs to increase student achievement.

Another study that supported the link between guided inquiry instruction and student achievement was conducted by Blanchard, Southerland, Osborne, Sampson, and Annetta (2010). These researchers examined the differences between traditional lab settings compared to those lab settings that were based on guided inquiry, and the effects on standardized measures of content knowledge, process, and scientific inquiry. A sample of middle school students (n = 642) and high school students (n = 1063) participated in this study. There were 12 middle school teachers and 12 high school teachers involved in this study. Teachers chosen for the inquiry group received a 6-week professional development course designed to assist teachers with methods of inquiry-based instruction. This research used a quasi-experimental pretest/posttest/delayed posttest design.

Teachers in the guided inquiry group implemented activities in which students were given a situation and questions to examine, but no instructions or lab sheets were distributed. Explicit instructions were not given to this treatment group. Teachers were told to answer student questions with a question and ask for an explanation from students. Teachers in the comparison group used a traditional, verification instructional approach (Herron, 1971). Through the verification approach, students were directed to follow explicit procedures and student questions were answered by the teacher. The posttest was a standardized measure of content knowledge, science process skills, and the nature of science. Data were analyzed using a hierarchical linear model for each of these areas with the only predictor being time.

The findings of this research suggested that students who received guided inquiry instruction showed significant gains in achievement on both the posttest and delayed posttest in content knowledge ($t = 6.09$ and $t = -5.03$, $p < .001$), science process skills ($t = 21.06$ and $t = -17.48$, $p < .001$), and the nature of scientific inquiry ($t = 13.26$ and $t = -12.84$, $p < .001$) as compared to those who were in traditional, verification-based science classes. When disaggregating the data by school, the high school inquiry group students outscored the traditional instruction group based on posttest and delayed posttest results ($t = 40.41$ and $t = -35.35$, $p < .001$). The researchers concluded that guided inquiry produced higher results and showed more growth at the high school level. Limitations cited by the researchers included exposure or lack of exposure of students and teachers to inquiry before the research.

Inquiry research in higher education. Research has been conducted to compare lab experiences in guided inquiry classrooms and lab settings that follow scripted labs.

Brickman, Gormally, Armstrong and Hallar (2009) examined the differences between traditional science settings compared to lab settings that were inquiry-based. This quasi-experimental study involved a sample of university students (n = 395). Students in the traditional setting followed a scripted lab design, whereas the treatment group conducted guided inquiry labs related to real-life scenarios.

The findings of this research suggested that students who received inquiry instruction showed gains in literacy, $F(1, 383) = 12.21$, $p < .001$, and science process skills, $F(1, 393) = 4.56$, $p < .05$, as compared to those who were in traditional science classes. This research supports the notion that an inquiry-based learning program has a significant effect on the process skills used in science, regardless of the level or age of students.

In addition to the research described that was conducted to measure the difference in achievement between guided inquiry and traditional means, Bryant (2006) examined the differences in student achievement between open-inquiry instruction and lecture-based instruction. A sample of middle school science and mathematics pre-service student-teachers (n = 51) participated in this study. These university students were currently enrolled in a conceptual physics course and met twice per week for 75 minutes each class lecture. These students also met twice per week for 75 minutes for laboratory sessions. A group of students experienced open inquiry activities and another group of students experienced non-inquiry activities in the form of lectures. Students were tested using exam questions based on the content presented.

The findings suggested that students who received inquiry instruction showed gains in physics content compared to those who were in the non-inquiry group ($t = 6.706$, $p < .005$). The researchers concluded that unguided inquiry laboratory investigations were more beneficial than traditional, lecture-based instruction. A limitation to this research was the lack of time provided for reflection and discussion at the conclusion of the open-inquiry activities.

There is also qualitative research that suggests the advantage of inquiry learning. Gengarelly & Abrams (2009) examined teachers' perceptions of inquiry, as well as how inquiry was implemented in secondary classrooms. The participants were graduate fellows (n = 15), who collaborated with teachers in the delivery of inquiry-based instruction. Instruction was based upon a district initiative to improve scientific literacy; a project called Partnerships for Research Opportunities to Benefit Education (PROBE). The fellows spent two days per week with these secondary teachers for a total of two years. The participants were interviewed three times each year. Upon analyzing the audiotape transcripts, the researchers developed themes from the data. These themes included, but were not limited to, approach to inquiry implementation and perceptions of implementing inquiry based on the impact of the teachers and school culture. Findings of this research indicated that teachers have more of a focus on higher levels of inquiry when given the opportunity to utilize these strategies in a collaborative environment over time.

Summary. The studies reviewed above provide a scope for inquiry's success in science classrooms. These studies included similar inquiry components that are mostly guided in nature. The cooperative, hands-on, and lab-based characteristics of inquiry are apparent in all studies, whereas these strategies are compared to traditional models that are lecture-based, textbook-based, and overall, teacher-directed. Results from these studies indicate that there is a clear connection to the benefits to inquiry instruction in elementary, middle level, secondary, and higher education.

Critical Thinking

By developing higher-level thinking skills in students, teachers can stimulate critical thinking, a process where students do not always arrive at the correct answer. Sternberg (1987) advocates ways that teachers can teach critical thinking and address this perception:

> Very often in critical thinking problems, there are no right answers. And even when there are, it is the thought process that counts. Ultimately, students who think well will be in a position to generate good answers, whereas students who generate good answers do not always think well. (p. 458)

Use of higher-level thinking strategies to stimulate critical thinking. Critical thinking is a "purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based" (Facione, 1990, p. 2). Miri, Uri, & Ben-Chaim (2007) investigated the use of teaching strategies that promoted higher-level thinking skills to determine if students' critical thinking in science was enhanced. An experimental pretest/posttest comparison group design was used for a sample of 177 high school students. The treatment group was introduced to teaching strategies that enhanced higher order thinking skills, such as question asking, self-investigating phenomena, open-ended inquiry experiments, and making inferences. The California Critical Thinking Skills Test (CCTST), the precursor to the *CM3*, was one of the instruments used.

The results of this study indicated that for four of the seven subscales of the CCTST, the treatment group scored significantly higher than the comparison group. Significant results were reported for the following subscales: truth-seeking ($F = 7.41$, $p < .01$), open-mindedness ($F = 8.08$, $p < .01$), self-confidence ($F = 4.37$, $p < .05$), and maturity ($F = 6.40$, $p < .01$). The subscales that did not produce significant results were: analysis, evaluation, and inference. The researchers concluded that developing higher-level thinking skills in the curriculum was important in order to stimulate critical thinking in science.

Research on the Suchman inquiry model. Research on inquiry models also demonstrates the benefits in promoting higher-level, critical thinking. Alshraideh (2009) used Suchmans' inquiry model to observe differences in critical thinking among university students ($n = 96$). This model uses a step-by-step method of training students to develop their thinking skills through asking questions. At the start of the semester, the model was introduced and students were provided with a problem that exemplified this process. This model was then used in a curricular context for the remainder of the semester. The students were trained for one hour, three times a week.

To identify differences between the groups, the researcher conducted a two-way ANCOVA, reporting statistical significance in critical thinking ($F = 19.214$, $p < .001$) using this type of inquiry learning program ($M = 36.4$; $SD = 6.6$) as compared to a traditional science program ($M = 31.4$; $SD = 4.6$). The researchers concluded that this model was successful in promoting critical thinking by fostering inquiry skills through the use of questioning.

The Suchman inquiry model (Suchman, 1968) is a key component in the treatment of this dissertation. In a recent database search, only four results were retrieved in this search, with only one of these as a primary source. Even though this model is a form of guided inquiry with clear connections to scientific investigations, there is limited research for the use of this model of instruction.

Promoting critical thinking at the middle school level. Research on critical thinking at the middle school level is important for science educators in promoting these skills while delivering the curriculum. Gunn & Pomahac (2008) investigated the impact of critical thinking of middle school science students using a pretest/posttest experimental design study. Two science classes were randomly assigned to the experimental or control groups. The sample (n = 50), consisted of seventh graders from a mid-sized Canadian school. The experimental group (n = 22) received instruction in guided critical thinking construction, while the control group did not receive this guidance during a six-month time period. Students in the experimental group were trained in differentiating between questions based on memory and critical thinking related to bioethical issues. These included the following topics: structural engineering, blood transfusions, and chemical warfare. The instrument used was *The Cornell Critical Thinking Test* (Level X).

The results of a one-way analysis of variance ANOVA indicated that utilizing structured critical thinking question stems increased critical thinking skills scores in the treatment group (M = 44.13; SD = 7.45) as compared to the control group (M = 43.71; SD = 9.05). Although these results were not significant, there was notable change of the experimental group from pretest (M = 42.29) to posttest (M = 44.13). Also, chi-square analyses of questions generated by the students produced significant findings ($p < .05$) related to the levels of questioning according to Bloom's taxonomy. The experimental group produced higher means for evaluation questions for each of the bioethical issue topics studied: Structural engineering questions (*Chi-Square* = 14.21, $p < .05$), blood transfusion questions (*Chi-Square* = 18.32, $p < .05$), and chemical warfare questions (*Chi-Square* = 27.84, $p < .05$). The researchers concluded that instruction utilizing guided critical thinking stems stimulates the generation of higher level questions and critical thinking overall. This research provides evidence to support the use of guided inquiry in this dissertation.

Creative Thinking

The methods and techniques used in the Creative Problem-solving (CPS) model (Treffinger & Isaksen, 1985) are based explicitly on the work of Osborn (1953) and Parnes (1967), with later applications through the work of Torrance (1972). Research conducted by Osborn (1953) focused on the importance of imagination and problem-solving and the processes associated with creative thinking. "Osborn's work became famous for introducing the concept of brainstorming, encouraging a free-flowing stream of thoughts and ideas, while temporarily withholding all criticism or judgment" (Treffinger & Isaksen, 1985). Although there are several similar models associated with CPS, the model refined by Treffinger & Isaksen (1985) is composed of six stages: mess-finding, data-finding, problem-finding, idea-finding, solution-finding, and acceptance-finding.

Creativity and science achievement. Lam, Yeung, Lam, & McNaught (2010) examined secondary school students (n = 311) who were a part of a two-year science enrichment program in Hong Kong. The *Torrance Test of Creative Thinking* (*TTCT*) was the instrument used in this pretest-posttest quantitative design. There were three phases of the science enrichment program. Phase 1 provided students with workshops on science content, various site visits to research labs, and practice with experiments. Phase 2 included a continuation of experimentation that extended from Phase 1 experiments. Phase 3 allowed students to conduct research according to a particular science topic. Students who were promoted into Phases 2 and 3 were compared to those students who only completed Phase 1. Upon conclusion of the program, *TTCT* scores were collected again, along with achievement scores. Findings suggested that there was a positive correlation between students' creativity and science achievement ($r = .294$, $p < .001$). Researchers also found that there was a significant difference in scores between the two groups of students studied ($t = -4.40$, $p < .001$). The researchers concluded that creativity is an important piece of learning in science.

Creative thinking approaches in science. Cheng (2010) conducted qualitative research to explore the impact of teaching creative thinking in science lessons. This study examined three instructional approaches used by secondary teachers for integrating creative thinking into regular science lessons. The researcher developed themes based on interviews, analyses of students' work, and in-depth lesson analyses. Each teacher taught using each of the three approaches. Teacher A adopted a science process approach; Teacher B implemented a science content approach; and Teacher C employed a science scenario approach. In the science process approach, the teacher was trained in open-inquiry processes utilizing the idea finding and problem finding components of CPS. In the content approach, creative thinking was developed through the application of science information. In the scenario approach, the teacher was trained in CPS tasks based on a science-related scenario. This research provided initial attempts to infuse creative thinking elements into science instruction by secondary teachers. Data were collected via teacher and student interviews, analyses of students' work, and in-depth lesson analyses of the teachers. The researchers analyzed these data by themes, such as content domination, time constraints, student abilities, and student interest.

By examining each of the three teacher case studies, Cheng reported that all approaches to stimulate creative thinking were useful in developing student creative thinking, and that the three teachers were successful to some extent. The teacher who focused on science content found that students improved the quality and quantity of writing hypotheses. The teacher who focused on science process reported that students produced high-quality creative writings that applied science concepts effectively. There was also some degree of imagination of the students observed by this teacher. The teacher who used CPS (scenario approach to instruction) found that she had improved her ability to stimulate divergent thinking and strengthen her students' problem solving skills. Most importantly, in all three cases, students reported in interviews that their interests in the science topics increased after the creative thinking activity. Overall, this study demonstrated the importance of using creative thinking strategies in the science classroom.

Research on Science Process Skills

Limited research was found that describes the effects of inquiry programs on the acquisition or development of science process skills. As described in detail earlier, the findings of Brickman, Gormally, Armstrong and Hallar (2009) suggested that students who received inquiry instruction showed gains in science process skills, $F(1, 393) = 4.56$, $p < .05$, as compared to those who were in traditional science classes. Also described earlier, the findings of Mattheis & Nakayama (1988) proposed that a laboratory-centered guided inquiry program had significant effects on science process skills in middle school students [$F(1, 82) = 8.44$, $p < .01$].

Hands-on, cooperative learning, and the science process. Bilgin (2006) investigated the effects of hands-on activities using cooperative learning on eighth grade students' science process skills. An experimental pretest/posttest comparison group design was used for a sample of 55 eighth grade students from two science classrooms. The treatment group was introduced to hands-on activities in a cooperative group setting, whereas the control group was taught through a teacher demonstration approach. The Science Process Skills Test (SPST) and Attitude Scale Toward Science (ASTS) instruments were used. Data were analyzed by conducting a multivariate analysis of variance (MANCOVA), where the pretests were used as the covariates.

The experimental group (M = 22.14; SD = 3.35) scored significantly higher than the control group (M = 16.52; SD = 3.46) on pretests for both instruments. The researcher found that there were significant differences in science process skills (F = .003, p < .05) and attitudes toward science (F = .253, p < .05) when using a hands-on, cooperative learning method of instruction as compared to teacher presentation of content. Bilgin concluded that this method of instruction developed science process skills and attitudes toward science in a positive manner.

Research on Science Projects

Studies conducted in the area of middle school science fair achievement are sparse. In an EBSCO database search using the search term, "middle school and science fair and achievement," a total of four results were retrieved. These four references provided characteristics of successful projects and were not primary sources. The following research studies represent some of the literature obtained as a result of extending the search outside the middle school level.

Science fair research design selection. Pyle (1996) examined the influences on science fair participant research design and success. His qualitative study focused on 22 finalists at the 44th International Science and Engineering Fair (ISEF). Students were approached prior to judging and asked to complete a brief questionnaire. The researcher chose this time because he felt that the students were well prepared to explain their projects to judges. Students chosen were from the eleventh and twelfth grade. The instrument used was researcher-designed. Of the 22 students in the study, 19 were named winners at the conclusion of the fair.

Findings suggested three important pieces of information. First, there was positive interaction between all students and their mentors. The researcher determined that students were motivated to work on these projects and contended that mentors and parents allowed students to take ownership over their project. Second, there were factors that influenced motivational orientation, such as intrinsic and extrinsic rewards. Lastly, Pyle found that students who were winners attributed their project strengths more toward internal influences, whereas non-winners cited external factors. The researcher concluded that research design selection in science fair projects did not appear to directly affect success at science fairs. However, students who conducted projects with non-experimental designs encountered barriers in their research.

Impact of problem-finding techniques on science fair projects. Levels of inquiry employed by students at state and national science competitions were reported by LaBanca (2008) in a qualitative study. His research provided guidance for teachers and researchers interested in the issues related to problem-finding in adolescents as they pursued their scientific investigations. The study examined open-inquiry, problem-finding strategies employed by students in grades 11-12 (n = 20) who presented at the 2007 Connecticut State Science Fair and the 2007 International Science and Engineering Fair. Students completed projects from each of these areas: (a) literature review; (b) technical; (c) technical with value; and (d) novel approach. Three teachers, three university mentors and two science fair directors were purposefully selected to participate. Data were triangulated using various methods: surveys, interviews, and document analysis. Findings suggested that the quality of science fair projects was directly impacted by the quality of the problem-finding techniques the students used. The researcher also found that problem-finding was influenced by the collaboration and communication of practicing scientists.

Generation of creative ideas for science fair projects. Student interests in science fair projects and their associated self-regulatory strategies for completion of these projects was reported by Delcourt (2008) in a qualitative study. School districts involved in this study employed Renzulli's Enrichment Triad Model (Renzulli & Reis, 1986), in which the development of creative productivity was emphasized. The sample was comprised of 10 students in Grade 9 through 12 from four different locations. These typical high schools were recommended by experts in the field of gifted education and the schools were not special schools for the gifted.

Multicase studies were analyzed and data were triangulated to avoid bias. Data were collected in the form of student interviews, student questionnaires, and parent questionnaires. These records were analyzed according to themes and categories. Findings suggest that secondary students' "involvement in their creative productive activities improved their self-regulatory behaviors and provided them with critical skills for today as much as for their future careers" (Delcourt, 2008). Furthermore, students used the following self-regulatory processes in providing advice to their peers on their projects: (a) intrinsic interest; (b) attention focusing; (c) learning goal orientation; (d) self-monitoring; (e) self-instruction; (f) self-efficacy; and (g) strategic planning.

Chapter Summary

A constructivist approach is the basis for all inquiry-based teaching and learning. The fundamental underpinnings of effective inquiry relates to theorists from progressive education. John Dewey was a pioneer for this type of instruction in its simplest form. Similarly, Jerome Bruner elaborated on the knowledge-getting process, which promotes problem solving and ultimately, critical thinking. By manipulating science content through effective inquiry instruction, students are provided with the ability to construct scientific meaning rather than simply repeating or memorizing scientific facts.

There are various viewpoints on what exactly constitutes an inquiry teaching method in science (Colburn, 2000; Dunkhase, 2003; Furtak, 2006; Herron, 1971; Manconi, Aulls, & Shore, 2008; Martin-Hansen, 2002; NRC, 1996). Based on the reported literature, researchers agree with the importance of the National Research Council's description of inquiry (NRC, 1996). Many researchers divide inquiry into levels, such as structured, guided, and open inquiry (Colburn, 2000; Dunkhase, 2003; Herron, 1971; Martin-Hansen, 2002).

Research supports the positive impact of inquiry-based activities on student achievement (Blanchard, Southerland, Osborne, Sampson, & Annetta, 2010; Chang & Mao, 1999; Mattheis & Nakayama, 1988; Panasan & Nuangchalerm, 2010; Randler & Bogner, 2002), but limited sources of information exist connecting this type of learning to creativity and science fair project achievement. This dissertation supports research in the past related to guided inquiry and creative problem solving, but more importantly, attempts to expand on the gaps found in literature related to inquiry in science and science fair achievement.

CHAPTER THREE: METHODOLOGY

The purpose of this study was to understand the impact of an inquiry-based science program on creative and critical thinking, in addition to science process skills linked to student involvement in scientific experimentation and science fair projects. This chapter provides details of the methodology used to examine this topic and includes the following sections: (a) research questions and hypotheses; (b) description of the setting and subjects; (c) description of the inquiry and direct instruction programs; (d) data collection and timeline; (e) instrumentation; (f) description of the research design; (g) description and justification of the analyses; (h) internal and external threats to the study; and (i) ethics statement.

Research Questions and Hypotheses

This research addressed the following questions:

1. Is there a significant difference in critical thinking skills, science process skills and creativity of middle school science students who participate in an inquiry-based program as compared to students who participate in a science program employing direct instruction?

   Directional hypothesis: Middle school science students who participate in an inquiry-based program will score significantly higher in critical thinking skills, science process skills and creativity as compared to those students who participate in a science program employing direct instruction.

2. To what extent and in what manner do critical thinking skills, science process skills, creativity, and program type predict science fair achievement?

Directional hypothesis: Critical thinking skills, science process skills, creativity, and program type will predict science fair achievement.

Description of the Setting and the Subjects

Although the school district was predominantly white (81%), there has been an increase in racial, ethnic, and economic diversity over the past seven years according to the Strategic School Profile for the district. The population is comprised of 81% white, 11% Hispanic, 3% black, 5% Asian, and less than 1% American Indian students. Furthermore, approximately 11% of students came from homes where English was not the primary language spoken (CSDE, 2008). The town had a population of approximately 18,000 people. The median household income for this community was $74,000.

All 690 middle school students in this small, suburban community in the northeast were asked to participate in the study. Consent was received from 229 students and parents for this sample of convenience. Table 5 describes the breakdown of students in the sample, resulting from the population in this school. Refer to Table 6 and 7 for a breakdown of the sample by gender and classroom. These students were currently enrolled in science courses at the middle school level. Seventh graders focused on life science, and eighth graders were taught earth science.

Table 5

Population and Sample Information

Group	Population *N*	Sample *n*	Percentage of the population %
Treatment	230	113	49
Grade 7	123	43	35
Grade 8	107	70	65
Comparison	227	116	51
Grade 7	119	68	56
Grade 8	108	48	44

Table 6

A Breakdown of Frequencies by Gender and Classroom for Participants in the Treatment Group

	Treatment	
	Males	Females
Grade 7 (Life Science)		
Classroom 1	3	2
Classroom 2	5	6
Classroom 3	7	4
Classroom 4	6	2
Classroom 5	4	4
Total	25	18
Grade 8 (Earth Science)		
Classroom 1	2	12
Classroom 2	5	10
Classroom 3	8	7
Classroom 4	5	8
Classroom 5	6	7
Total	26	44
Grand Total	51	62

Table 7

A Breakdown of Frequencies by Gender and Classroom for Participants in the Comparison Group

	Comparison	
	Males	Females
Grade 7 (Life Science)		
Classroom 1	6	7
Classroom 2	5	8
Classroom 3	8	5
Classroom 4	7	9
Classroom 5	6	7
Total	32	36
Grade 8 (Earth Science)		
Classroom 1	4	5
Classroom 2	6	4
Classroom 3	3	7
Classroom 4	5	2
Classroom 5	5	7
Total	23	25
Grand Total	55	61

Four science teachers, two at each grade level participated in the study. (See Table 8 for characteristics of the teachers in the study.) Two of these teacher participants, one per grade level, were randomly assigned to the group that presented the curriculum for an inquiry program in science that was implemented over a 19-week period. The teachers assigned to the comparison group presented a curriculum through direct instruction. (Over the years, science classes have been taught through a direct instruction model, with selected lessons taught through guided inquiry.) All classes per grade level and group were taught by the same teacher. For example, all five classes in the seventh grade treatment group were taught by teacher A. Each teacher instructed each of their five classes for 40 minutes per day, unless there was an assembly or an interruption to the schedule.

Table 8

Teacher Characteristics

Teacher	Grade level	Group	Years experience
Teacher A	7th grade	Treatment	37
Teacher B	8th grade	Treatment	1
Teacher C	7th grade	Comparison	9
Teacher D	8th grade	Comparison	5

The groups were equivalent in terms of general demographics at the start of the study based on the premise that each intact class from the treatment and comparison groups was approximately equal with respect to ability, gender, number of special education students and English language learners.

The science department at this middle school employed a curricular approach where the seventh grade focused on life science and the eighth grade addressed earth science. See

Table 9 for a description of the middle school curriculum framework, which is linked to the standards set forth by the state of Connecticut.

Table 9

Middle School Curriculum Overview for Grades 7 and 8

Grade level	Content and Curriculum Standards			
7th Grade	Ecosystems	Structure and Function of Cells and Human Body Systems	Heredity and Evolution	State Inquiry Standards
	Long Island Sound	Food Spoilage by microbes		Science Fair Project
8th Grade	Sun's Energy	Landforms	Solar system	State Inquiry Standards
	Seasonal Weather Patterns	Water and human impact		Science Fair or Research-based Project

Science fair projects as part of the science curriculum. The school's science fair is connected to the science curriculum by content area and grade level, in addition to following the state experimental inquiry standards at each grade level. The science fair is a three-night event that is open to the public. All middle school students participate in the fair on separate evenings during the second week of March. The science fair projects are traditionally not scored by classroom teachers for competition purposes nor are prizes distributed. However, these projects are scored as a project grade at each grade level by the classroom teachers.

Students are encouraged to enter a regional science fair (when held) in order to compete for entrance to the state science fair. It is the state science fair rubric that is used by teachers as a means for scoring in the district. The event is an exposition of student work to be shared with parents and community members. All seventh grade students are required to work on and submit a science fair project. The eighth grade students have the choice of designing an experiment that measures variables, or completing a research project on an area of focus within the grade level curriculum. For the purposes of this research, only those projects representing experiments produced by eighth grade students were scored. There were 45 students who chose to complete research papers as opposed to experiments, reducing the number of overall participants in the study to n = 184. All projects of seventh grade students were scored because all of these represented experiments.

Description of the Inquiry Program

The treatment in this research was developed to promote critical and creative thinking skills of students so that they would produce high quality science fair projects. The two main instructional methods used in the treatment were the Suchman Inquiry model (Suchman, 1968) as described by Gunter, Estes, and Schwab (2003) and the Creative Problem-solving (CPS) model (Treffinger & Isaksen, 2005). A series of inquiry activities were also utilized which included guided inquiry labs, inquiry skills worksheets, and inquiry process reflections.

Professional development. Before the treatment was employed by the teachers, a professional development workshop was provided by both the researcher and an expert in the field of creativity. This session provided teachers with a clear description of the program and modeled effective delivery of inquiry-based strategies. A lecture in conjunction with a powerpoint presentation (Appendix A) served as a framework based on theory and research. The presenters also provided an overview of all components of the program by reviewing sample lessons as if the teachers were their students. The Suchman Inquiry model (Suchman, 1968) template was shared with teachers and an example was assigned, so teachers would have a clear understanding of how to implement this type of lesson. The CPS model (Treffinger & Isaksen, 2005) was shared and explained. Lastly, a demonstration lesson was conducted for students in a seventh grade classroom and then in an eighth grade classroom by an expert in creativity, highlighting how to use the CPS process to brainstorm science fair topic ideas.

Implementation of the Suchman inquiry model. The Suchman model is a 6-step model that incorporates a process by which students select a problem (puzzling situation), conduct research and gather information, develop a hypothesis, explain a theory, and analyze and evaluate their process (Suchman, 1968). In this study, the problem was either provided by the teacher, or determined by the student, based on the specific lesson.

Each time used, students collected all data and ideas either in an inquiry journal or on handouts. These documents and journals were stored in the classroom and served as artifacts of student work that teachers shared with the researcher at weekly meetings. The

Suchman inquiry model was used twice in Grade 7 and three times in Grade 8 throughout the study. This model was implemented in Grade 7 during weeks 4 and 13 out of the 19-week program. The model was used in Grade 8 during weeks 6, 11, and 18. See Appendix B for the adapted template used in this program. Each student involved in the treatment group completed each of the Suchman activities in his or her inquiry journal. See Appendix C for a detailed description of each Suchman activity used in this study.

Implementation of CPS. The CPS model also served as a process for students to develop thinking skills. This process included the following areas: Mess-finding, data-finding, problem-finding, idea-finding, solution-finding, and acceptance-finding (Treffinger & Isaksen, 1985). In order to accommodate the teachers and students, the researcher revised and adapted the CPS forms in order to streamline the most important components of CPS needed for this study and for the science fair process. See Appendix D for an explanation of these adapted forms.

The students were first introduced to mess-finding, which involves "probing interests, experiences and concerns to consider a number of general topics which might serve as possibilities or starting points for CPS" (Treffinger & Isaksen, 1985, p. 3). These problems, interests, and topics were in the form of science fair project ideas. Next, data-finding allowed the students to gather information using "5 W's and an H" (Who, What, Where, When, Why, How). The students organized their brainstormed ideas into a chart. In problem-finding, students considered problem statements using the "In What Ways Might" (IWWM) framework, again organizing their responses into a chart. In the Idea-finding stage, students were asked to generate more ideas based on the problem questions created at that point in the process. The SCAMPER model (Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate, and Rearrange) (Eberle, 1971) was used in this step for the treatment. Upon completing a SCAMPER chart, the students moved to solution-finding by taking these ideas and developing a list of possible solutions. Students prioritized these ideas by looking at cost, time, availability of materials, motivation, and any other factors that they felt could impact their solution. Lastly, the students generated a plan of action that served as the acceptance-finding stage of the model.

The CPS model was implemented twice in both the seventh and eighth grades. The process was used at the onset of the research (weeks 1 and 2) for students to brainstorm potential science fair topic ideas, and again at the conclusion of the school's science fair (weeks 16 and 17) as a means of brainstorming additional ideas for future science fair projects. The CPS work completed by the students was also collected in the inquiry journal. Components, strategies, and document templates employed by teachers adapted from the CPS model are found in Appendix D. The specific components of CPS chosen by the researcher were those that were most appropriate for the inquiry program, which foster creativity through the brainstorming process. Each student in the treatment group completed the CPS process and related work in their inquiry journals at each interval that CPS was administered.

Implementation of inquiry activities. A series of guided inquiry labs, review worksheets, and a reflection were administered periodically. These activities included a combination of state embedded tasks, researcher-designed lab activities, and teacher-designed inquiry labs, all of which were aligned with state science frameworks. Embedded tasks are required labs by the State that are directly linked to state content standards.

Worksheets were administered at specific intervals in the program to provide a review of inquiry skills. The skills covered in these worksheets were: posing questions, observing, inferring, developing a hypothesis, predicting, and controlling variables. Four inquiry worksheets were administered during weeks 3 through 11. One week after completion of a worksheet, feedback was given to students either by the classroom teacher or the researcher. The feedback was based on the discussion between teachers and the researcher at the weekly meetings. The researcher provided a list of important feedback items for the teacher to share with the students. The reflection journal entry was assigned to treatment students during week 15 in both the seventh and eighth grades.

Students in the treatment group designed guided inquiry experiments throughout the research under the facilitation of their teacher. The purpose of these labs was to develop questions, formulate hypotheses, design a procedure, analyze results, and draw conclusions. The completion of this task was evident in the written lab report. The lab format for these activities was completely aligned with the national and state science inquiry standards and the skills related to the Suchman model. The treatment group designed their own experiments. These students brainstormed possible problem questions, developed hypotheses for the investigation, wrote their own procedures, completed a data table, graph, and conclusion. The students also created questions for further study.

Inquiry skills review and reflection. Student work was shared on a weekly basis with the researcher and timely feedback was provided for students by each teacher in the treatment group. During week 15, both seventh and eighth grade students completed a journal entry, reflecting on their inquiry process along with strengths and weaknesses associated with their acquired skills. See Appendix E for the inquiry reflection prompt created by the researcher.

Monitoring of the inquiry program. On a weekly basis, the researcher verified how each teacher was administering the treatment. Responses provided information for the researcher regarding instruction and progress related to daily lessons as well as the science fair process.

In addition, all student work from the treatment group was collected and feedback was provided to students within 1-2 weeks. Student work was in the form of Suchman Inquiry investigations, CPS worksheets and/or journal work, inquiry worksheets, as well as lab reports from guided inquiry investigations. This information provided a focus for how students progressed and provided evidence that teachers in the treatment group were using the inquiry program strategies proposed at the onset of the research. Upon discussion of student work with each teacher in the weekly meetings, the researcher presented feedback for the teachers to use with their students.

Description of the Direct Instruction Program

The students in the direct instruction group followed the same content in the middle school curriculum. See Table 9 for this curriculum overview. Teachers in the comparison group taught using lecture as the primary method of instruction. Teachers presented powerpoint lessons on content areas, assigned worksheets, performed demonstrations, and monitored student progress through quizzes and tests that assessed the recall of knowledge.

The students in the comparison group also performed labs periodically, however, the implementation of these labs differed from that of the treatment group. Students were provided with a question for the basis of their lab investigation. Students created a hypothesis, listed materials, and were given the procedural steps to take in order to complete the lab. Data were collected using data tables and organized in graphs, and four conclusion questions were answered, which were recall-based in nature. Although two of these labs were the same required labs from the State (in terms of content), the labs were administered by using guided and open inquiry approaches. This was different from the procedures used in the direct instruction group.

The teachers in the direct instruction program assigned science fair projects to the students, as did the teachers in the treatment group. However, the students were assigned a due date for a topic and there was little guidance from the teacher in developing a project idea. Other than the introduction and initial discussion of expectations for the science fair as well as the collection of the final project, there was no interaction between these teachers and their students, unless students inquired about needing extra help.

Monitoring of the direct instruction group. The researcher verified strategies used by the comparison group teachers through informal, bi-weekly meetings or by email correspondence on a weekly basis. Responses provided information for the researcher regarding the method of direct instruction and progress related to lessons as well as the science fair process.

Data Collection Procedures and Timeline

During the 19-week study, the researcher had weekly correspondence with teachers to verify that the treatment was being carried out with fidelity. At each meeting, student work was the focus of the discussion. The teachers in the treatment group and the researcher examined various samples of exemplary work during this time, along with work that was in need of improvement. Student work was in the form of inquiry lab reports, journal entries, and science fair project board displays. See Figure 1 for an overview of the timeline used in this study.

The researcher also met with the two teachers implementing direct instruction. Specifics were discussed regarding the delivery of curriculum, style of teaching, and types of assessments completed. Selected student work was also viewed to check the progress of the comparison group in terms of science fair project preparation.

Science Fair and Inquiry Introduction (Weeks 1-3)
▪ Introduction, modeling, and use of CPS ▪ Introduction, modeling, and use of Suchman inquiry
Science Fair Process and Experimentation (Weeks 4-14)
▪ Student check-in points for science fair ▪ Feedback on work completion ▪ Implementation of Suchman inquiry activities ▪ Completion of student-designed experiments and lab reports ▪ Completion of inquiry review worksheets
Conclusion of the Science Fair Process (Weeks 15-19)
▪ Generation of new science fair ideas for future science fairs using CPS ▪ Implementation of Suchman inquiry activities ▪ Completion of student-designed experiments and lab reports ▪ Completion of reflection-based journal entries

Figure 1. Treatment Characteristics and Timeline

At week 14, seventh and eighth grade science fair projects were scored by one or more of the 13 raters who were trained in using the *Connecticut Science Fair Rubric*. By selecting raters other than the classroom teachers, the chance for scoring bias was reduced. At week 19, posttests were administered and data were organized and analyzed. Refer to Table 10 for the complete timeline of activities for the study.

Table 10

Timeline of Activities

		Grade level	
Week	Date	Grade 7	Grade 8
1	November 29 – December 3	▪ Professional development workshop ▪ Introduction to the CPS model and related worksheets ▪ Brainstorm lists of possible science fair ideas using CPS ▪ Documentation of ideas using CPS in journals	▪ Professional development workshop ▪ Introduction to the CPS model and related worksheets ▪ Brainstorm lists of possible science fair ideas using CPS ▪ Documentation of ideas using CPS in journals
2	December 6 – December 10	▪ Continuation of preliminary research for science fair project topics of interest using CPS worksheets	▪ Continuation of preliminary research for science fair project topics of interest using CPS worksheets
3	December 13 – December 17	▪ Science fair project typed proposal due ▪ Student/teacher conferencing about project idea ▪ Accept or not accept idea. (If not accepted, new ideas are chosen.) ▪ Completion of inquiry worksheet #1: Posing questions	▪ Science fair project typed proposal due ▪ Student/teacher conferencing about project idea ▪ Accept or not accept of idea. (If not accepted, new ideas are chosen.) ▪ Completion of designed inquiry lab #1: State Embedded Task, “Dig In” (See Appendix C)

Table 10 (continued)

Timeline of Activities

		Grade level	
Week	Date	Grade 7	Grade 8
4	December 20 – December 24	▪ Completion of Suchman Inquiry investigation #1: Blood test analysis (Researcher-designed) ▪ Independent work on science fair project ▪ Feedback given for inquiry worksheet #1	▪ Completion of inquiry worksheet #1: Posing questions. ▪ Independent work on science fair project
5	January 3 – January 7	▪ Independent work on science fair project	▪ Feedback given for inquiry worksheet #1 ▪ Independent work on science fair project
6	January 10 – January 14	▪ Completion of inquiry worksheet #2: Observing ▪ Science fair process check-in point: Conference with teacher and reflection	▪ Completion of Suchman Inquiry investigation #1: Bacterial growth (Researcher-designed) ▪ Science fair process check-in point: Conference with teacher and reflection
7	January 17 – January 21	▪ Completion of inquiry worksheet #3: Developing hypotheses ▪ Continuation of independent work on science fair project ▪ Feedback given for inquiry worksheet #2	▪ Completion of inquiry worksheet #2a: Observing and worksheet #2b: Inferring ▪ Continuation of independent work on science fair project
8	January 24 – January 28	▪ Completion of inquiry lab #1: Huff and Puff, respiration (Teacher-designed; see Appendix C) ▪ Continuation of independent work on science fair project	▪ Completion of inquiry worksheet #3: Developing hypotheses ▪ Feedback given for inquiry worksheet #2a and 2b ▪ Continuation of independent work on science fair project

Table 10 (continued)

Timeline of Activities

		Grade level	
Week	Date	Grade 7	Grade 8
9	January 31 – February 4	▪ Continuation of independent work on science fair project ▪ Feedback given for inquiry worksheet #3	▪ Completion of inquiry lab #2: Fluff and puff: A cloud making lab (Teacher-designed; see Appendix C) ▪ Continuation of independent work on science fair project ▪ Feedback given for inquiry worksheet #3
10	February 7 – February 11	▪ Completion of inquiry worksheet #4: Predicting ▪ Continuation of independent work on science fair project	▪ Completion of inquiry worksheet #4: Predicting ▪ Continuation of independent work on science fair project
11	February 14 – February 18	▪ Completion of inquiry lab #2: State Embedded Task "Feel the Beat" (See Appendix C) ▪ Feedback given for inquiry worksheet #4	▪ Completion of Suchman Inquiry investigation #2: Septic systems and microorganisms (Researcher-designed; see Appendix C) ▪ Science fair process check-in point: Conference with teacher and reflection ▪ Feedback given for inquiry worksheet #4
12	February 21 – February 25	▪ Science fair project due on February 24th. Conference with teacher and reflection	▪ Generation of puzzling situations (from Suchman investigation #2) and sharing of work with peers ▪ Science fair project due on February 24th. Conference with teacher and reflection
13	February 28 – March 4	▪ Completion of Suchman Inquiry investigation #2: Bacterial growth (Researcher-designed) ▪ Presentation of select science fair projects in the classroom as time permits	▪ Completion of inquiry worksheet #5: Controlling variables ▪ Presentation of select science fair projects in the classroom as time permits

Table 10 (continued)

Timeline of Activities

		Grade level	
Week	Date	Grade 7	Grade 8
14	March 7 – March 11	▪ Presentations at the science fair	▪ Presentations at the science fair ▪ Feedback given for inquiry worksheet #5
15	March 14 – March 18	▪ Completion of journal entry: Students reflect on their scientific process – a checklist of science process skills is given for students to complete first as a graphic organizer. Next, students write a 1-paragraph reflection in their notebooks based on the brief survey that they completed (See Appendix E) ▪ Feedback on projects (from classroom teachers)	▪ Completion of journal entry: Students reflect on their scientific process – a checklist of science process skills is given for students to complete first as a graphic organizer. Next, students write a 1-paragraph reflection in their notebooks based on the brief survey that they completed (See Appendix E) ▪ Feedback on projects (from classroom teachers)
16	March 21 – March 25	▪ Use of the CPS process a second time to brainstorm ideas for next year's or future science fairs ▪ Ideas are recorded in journal or on CPS worksheets	▪ Use of the CPS process a second time to brainstorm ideas for next year's or future science fairs ▪ Ideas are recorded in journal or on CPS worksheets
17	March 28 – April 1	▪ Continuation of CPS process to brainstorm ideas for next year's or future science fairs ▪ Ideas are recorded in journal or on CPS worksheets	▪ Continuation of CPS process to brainstorm ideas for next year's or future science fairs ▪ Ideas are recorded in journal or on CPS worksheets ▪ Student-designed Inquiry lab #3: Friction Foes: An investigation of avalanches and friction (Teacher-designed; see Appendix C)

Table 10 (continued)

Timeline of Activities

		Grade level	
Week	Date	Grade 7	Grade 7
18	April 4 – April 8	▪ None	▪ Completion of Suchman Inquiry investigation #3: Temperature Change and Global Warming (Teacher-designed; see Appendix C)
19	April 11 – April 15	▪ Remaining assessment feedback given to students ▪ Administration of posttests	▪ Remaining assessment feedback given to students ▪ Administration of posttests

Instrumentation

Data were collected using five standardized instruments, the *California Measure of Mental Motivation* (*CM3*) (Giancarlo, 2010), The *Diet Cola Test* (*DCT*) (Fowler, 1990), The *Earthworm Test* (Adams & Callahan, 1995), *the Connecticut Science Fair Rubric* (CSF, 2006), and the *Torrance Test of Creative Thinking* (Torrance, 1966). Additionally, inquiry-based science labs were assigned and journals were collected. The work related to these activities was reviewed to monitor the progress of the treatment group.

California Measure of Mental Motivation (CM3). This instrument provided a measure of critical thinking. "The *CM3* was developed to capture measures of the personal attitudes that collectively orient a person toward learning and reflective thinking" (Giancarlo, 2010, p. 2). The purpose of administering the *CM3* was to evaluate the critical thinking levels before and after an inquiry treatment was administered. This survey measured dispositions toward critical thinking and mental motivation. The dispositions measured by this instrument are the characteristics of critical thinking that are found during the process of inquiry learning and experimentation.

Items for the *CM3* were developed after reviewing literature as well as adapting selected items from the *California Critical Thinking Disposition Inventory* (*CCTDI*). The *CM3* instrument has five scales: Mental Focus, Learning Orientation, Creative Problem-solving, Cognitive Integrity, and Scholarly Rigor. See Table 11 for a list of characteristics related to these scales.

Table 11

Five Scales of the CM3

Scale	Characteristics Related to the Scale
Mental Focus	Diligent
	Focused and systematic
	Task-oriented, organized, and clear-headed
Learning Orientation	Learning for learning's sake
	Learning process valued
	Engaged and take active interest in school
Creative Problem Solving	Intellectually curious, creative, and imaginative
	Preference for the challenging and complicated
Cognitive Integrity	Motivated and use of thinking skills
	Truth-seeking and open-minded
	Comfortable with challenge
Scholarly Rigor	Hard working
	Detailed learning through complex or abstract material

Note. Giancarlo (2010).

Scores are reported based upon a 50-point metric. The items are Likert-type, with four categorical response options, and scales ranging from strongly disagree to strongly agree. Scores ranging from 0 – 9 points represent individuals who are "strongly negatively opposed" (Giancarlo, 2010, p. 26) to a particular characteristic; scores ranging from 10 – 19 reflect "somewhat negative" perceptions (Giancarlo, 2010, p. 26); scores in the 20 – 30-point range are considered to be “ambivalent;” (Giancarlo, 2010, p. 26) scores in the 31 to 40-point range are “somewhat disposed” (Giancarlo, 2010, p. 26) toward the topic; and scores of 41 and above are “strongly disposed” to the attribute (Giancarlo, 2010, p. 26).

Validity and reliability of the CM3. The authors reported a collection of three separate studies as evidence of reliability and validity for the *CM3* (Giancarlo, Blohm, & Urdan, 2004). Two of the studies were conducted in Northern California and included both male and female high school students from diverse backgrounds (Giancarlo, Blohm, & Urdan, 2004). The third study was performed in the Midwest and involved predominantly Caucasian females (Giancarlo, Blohm, & Urdan, 2004). Internal consistency reliability scores were obtained using Cronbach’s alpha coefficient and ranged from .79 to .83 across the various studies. Reliability estimates for he subscales were .79 to .83 for mental focus, .79 to .83 for learning orientation, .70 to .77 for creative problem-solving, and .53 to .63 for cognitive. Reliability estimates are not available for scholarly rigor, as this component was added to the *CM3* instrument in 2006.

Evidence for criterion-related validity was reported by the authors (Giancarlo, Blohm, & Urdan, 2004). All four scales of the *CM3* resulted in statistically significant positive correlations, ranging from $r = .47$ to $r = .67$ ($p < .01$) when correlated with various measures of student motivation, behavior, and achievement (Giancarlo, Blohm, & Urdan, 2004).

Predictive validity was examined by correlating *CM3* scores with standardized test scores and grade point average (Giancarlo, Blohm, & Urdan, 2004). The two strongest relationships were found between scores on the Creative Problem-Solving scale and performance on the Math subtest of the SAT9 ($r = .33$, $p < .01$). Another strong relationship was found between scores on the Cognitive Integrity scale and performance on the Reading subtest of the SAT9 ($r = .43$, $p < .01$). Lastly, GPA was significantly related to the Mental Focus scale ($r = .35$, $p < .01$).

The Diet Cola Test (DCT). The *DCT* (Fowler, 1990) was used for assessing science process skills in elementary and middle school students. Students were asked one open-ended question as a pretest: "How would you do a fair test of this question: Are bees attracted to diet cola?" (Form A). Permission to use this instrument is located in Appendix F.

Scoring is conducted by using a checklist of 13 science process skills which include but are not limited to: observing, hypothesizing, repeat testing, measuring, collecting data, making conclusions, and controlling variables. The rater scores the assessment by giving zero points for each skill category if the student does not include the science process skill. The rater gives one point for each skill if the student has incorporated it in the design of the experiment. Two points were awarded when two or more indications of the specific skill are included in the design. For example, if a student includes one hypothesis in his or her response, he or she obtains one point. If two or more hypotheses are presented two points are awarded. The total points are tallied for an overall score.

Validity and reliability of the DCT. Two studies were conducted to establish reliability and validity for this instrument (Fowler, 1990). Students were randomly assigned to complete either Form A or Form B. Test-retest reliability produced a result of .76, $p < .01$ after a 10-week interval. The researchers established interrater reliability (round 1, $r = .96$, $p < .01$; round 2, $r = .90$, $p < .01$) in that 50 completed tests were chosen at random and scored among 4 raters.

Convergent and discriminant validity were established by means of two studies. The first study produced the following results: "weak patterns in correlations were not sufficient to suggest use for making decisions about specific aptitude of specific individuals" (Adams & Callahan, 1995). Therefore, study two was conducted and discriminant validity was established. "The test does not differentiate between genders, making it a practical measure for classroom use" (Adams & Callahan, 1995). The instrument exhibited content validity for types of science process skills depicting a match between the task and its indicators of success. DCT scores were significantly related to various measures of process skills: Group Embedded Figures Test (GEFT), ($r = .26$, $p < .01$); Test of Basic Process Skills (TBPS), ($r = .19$, $p < .001$); and the Iowa Test of Basic Skills (ITBS), ($r = .14$, $p < .05$).

The Earthworm Test. This assessment is Form B of the science process skills test used in this study. Students were asked one open-ended question as a posttest: "How would you do a fair test of this question: Are earthworms attracted to light?" (Adams & Callahan, 1995). Permission was given to use this instrument in this research. Refer to Appendix G for this correspondence. Scoring is conducted by using the same checklist of science process skills and the same scoring system used in the *Diet Cola Test* (Fowler, 1990).

Validity and reliability of the Earthworm Test. No validity or reliability studies have been published for this instrument. However, it was designed in the likeness of the *DCT* and authors of these instruments have communicated regarding the components and design. See Appendix G for this correspondence.

Connecticut Science Fair Rubric. This instrument is used for the Connecticut Science Fair (CSF; 2006) each March. This rubric is modeled after the rubric employed by the International Science and Engineering Fair (ISEF; 2010) and contains the following areas: scientific thought/engineering goals, creative ability, thoroughness, skill, and clarity (See Appendix H). Scoring is calculated by category as well as an overall score of 100.

***Validity and reliability of the Connecticut Science Fair Rubric*.** Inter-rater reliability was established for this science fair project instrument. Cronbach's alpha was calculated to be .805 (F. LaBanca, personal communication, September 25, 2010). The instrument has both content and construct validity in that it has been developed and modified by experts. The rubric has been used by practicing scientists and engineers to score science fair projects (CSF, 2006). Furthermore, the objectives of this rubric align with the objectives of the science fair process and the *CSF Rubric* matches the ISEF rubric for each subscale.

For this study, two to three raters scored each science fair project. A total of 13 raters scored the science fair projects. Each of these raters was trained in the use of the rubric before the science fair. Inter-rater reliability was established for the items, which correspond to each subscale. Refer to Table 12 for the Cronbach's alpha for each science fair rubric subscale for two and three raters.

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Table 12

Inter-rater Reliability for Science Fair Achievement Scores

		Cronbach's Alpha	
Item	Science Fair Rubric Subscale	Two raters	Three raters
1	Scientific Thought	.877	.858
2	Creative Ability	.836	.812
3	Thoroughness	.853	.806
4	Skill	.821	.889
5	Clarity	.574	.719
1-5	Items 1-5 above	.965	.973
	Overall Rating of Summed Scores	.941	.965

Note. There were 184 science fair projects that were rated by at least 1 rater. There were 61 projects that were rated 2 times by different raters. There were 7 projects that were rated 3 times by different raters.

The Torrance Test of Creative Thinking (TTCT). The figural form of this instrument was used in this study. Specifically, Figural Form A was used for the pretest administration and Figural Form B was administered for the posttest. The purpose of the *TTCT* Figural test was to measure various facets of creativity: fluency, originality, elaboration, abstractness of titles and resistance to premature closure (Torrance, 1966). Only the overall scores for the pre- and posttest were measured and reported in this study. This instrument was used in the research to capture changes in the creative process, especially in terms of fluency and originality. The *TTCT* Figural test format includes three activities: picture construction, picture completion, and lines (Torrance, 1966). Scoring was calculated by establishing points to determine a raw score. Scores were based on norm referenced data from over 15,000 subjects who were administered this assessment. For this age group, a standard score of 110 translates to the 50th percentile.

Validity and reliability of the TTCT. The *TTCT* has an established reliability ranging from .86 - .99 based on 100 Verbal and 100 Figural tests (Torrance, 1981). Most of the coefficients fall within the .90s. Test-retest reliability scores fall in the range of .60 to .70. In terms of validity, use of this instrument has added to its construct validity over the past 35 years. The instrument has established predictive validity in that three of the *TTCT* subscales (fluency, flexibility, and originality) correlated significantly with quantity and quality of creative achievements ($r = .39$ to $r = .48$, $p < .01$; Torrance, 1972). Concurrent validity was established for the *TTCT* when correlating the *TTCT* with the Spatial Test of Primary Mental Abilities ($r = .36$, $p < .001$), and the Gordon Test of Visual Imagery Control ($r = .30$, $p < .01$). The results of subsequent studies of the TTCT confirm the reliability and validity of this instrument (Torrance, 1981).

Inquiry-based labs. A series of inquiry-based labs were used throughout the research as a means of monitoring the progress of the treatment group. In total, three labs were instituted at the eighth grade level and two labs were administered at the seventh grade level. One of these labs per grade level was termed an embedded task, developed by the state and modeled after both national and state standards. Embedded tasks are required by the state and directly linked to content standards (CSDE, 2004). See Appendix C for more detail about the labs. Student work from these assignments was organized and stored in journals. In addition to the embedded tasks, other inquiry-based labs were instituted that were researcher and teacher-generated and based on the major components of the state inquiry standards. These labs were similar to the framework of the embedded tasks, containing the same lab sections.

Description of the Research Design

The research study was a quasi-experimental pretest-posttest comparison group design, as appears in Table 13. There was no random selection or random assignment of subjects (n = 229) to comparison and experimental groups. Intact groups were utilized. Four teacher participants, two per grade level, were randomly assigned to an instructional strategy (inquiry or direct instruction). For the first research question, five dependent variables, the five scales of the *CM3* instrument, were measured before and after implementing the treatment in this study. For the second research question, the predictor variables were the posttest scores for critical thinking, science process skills, and creativity, as well as program type. The criterion variable was science fair achievement as measured by the *Connecticut Science Fair Rubric*.

Table 13

Pretest-posttest Comparison Group Research Design

Group	Pretest	Treatment	Posttest
Experimental group (Inquiry instruction)	O	X	O
Comparison group (Direct instruction)	O		O

Relationship between Science Fair Rubric, Instruments, and Treatment

The components of the *Connecticut Science Fair Rubric* (*CSF*, 2006) are closely associated with all other instruments utilized in this study. The design of research question two was based upon these connections. This rubric included five components: Scientific Thought, Creative Ability, Thoroughness, Skill, and Clarity.

The Scientific Thought component of the *CSF Rubric* was developed to represent various elements of the scientific process. The skills associated with this component of the rubric are also directly related to the 12 skills (Adams & Callahan, 1995) associated with the elements of the assessments utilized to measure various science process skills incorporated into the *Diet Cola Test* (Fowler, 1990) and the *Earthworm Test* (Adams & Callahan, 1995). For example, the scoring guide for the science process skills instruments includes identification of the problem, evidence of a procedural plan, and data supporting conclusions. These are science process skills that are components of the *CSF Rubric* and the *Diet Cola* and *Earthworm Tests*. The Mental Focus subscale of the CM3 describes people as organized, systematic, focused, and task-orientated, similar to the characteristics of those who exhibit Scientific Thought.

In addition to the process and completion of a science fair project, the Scientific Thought component of the *CSF Rubric* was targeted through use of various inquiry labs, where students designed their own experiments based on the content area. Suchman inquiry activities also related to the use of skills important for Scientific Thought represented on the *CSF Rubric*. Through these activities, students followed a structured sequence of steps that stimulated critical thinking through questioning.

The Creative Ability component of the *CSF Rubric* related to the subscales of the *TTCT* Figural Forms with the common construct being originality. Science fair raters were trained in looking for students' originality in selecting the problem, developing a plan to solve the problem, and interpreting the data, according to the rubric. The Creative Problem Solving subscale of the *CM3* also relates to the *CSF Rubric*. Giancarlo (2010) described the Creative Problem Solving subscale by defining individuals as being intellectually curious, creative, imaginative, ingenious, and having a preference for challenging, complicated, and novel activities. By utilizing the Creative Problem Solving (CPS) model as part of the treatment, these characteristics were stimulated.

The *CSF Rubric* components of Thoroughness, Skill, and Clarity can be grouped together in order to provide a direct connection to instruments and the treatment. These concepts link to the *CM3* and its subscales of Mental Focus, Learning Orientation, Cognitive Integrity, and Scholarly Rigor. The characteristics associated with these subscales of the *CM3* include being systematic, focused, motivated, and valuing evidence gathering while having a disposition toward detailed learning. The *CSF Rubric* component Thoroughness characterizes projects to be systematic, complete, and evident of a detailed literature search. The *CSF Rubric* components Skill and Clarity are characterized by precise computation, design skills, and evidence, in addition to a focused, orderly display of data and formed conclusions. These *CSF Rubric* components are also related to the elements of the science processes defined by Fowler (1990) and Adams & Callahan (1995).

The Thoroughness, Skill, and Clarity components are associated with the treatment primarily through the *CPS* process in generating ideas, as well as in the overall science fair process upon completion of the project and presentation at the science fair. The Suchman inquiry activities also provided a scaffold for guided inquiry through the acquisition of skills to problem-solve using the characteristics of Thoroughness, Skill, and Clarity. See Table 14 for a summary of the relationship between all components of the *CSF Rubric*, the instrumentation, and the treatment.

Table 14

The Relationship Between Science Fair Components, Instrumentation, and Treatment

CSF Rubric Component	Instrumentation	Treatment
Scientific Thought	▪ DCT/Earthworm Test ▪ CM3, Mental Focus	▪ Inquiry Labs ▪ Science Fair Project ▪ Suchman Inquiry Activities
Creative Ability	▪ TTCT ▪ CM3, Creative Problem Solving	▪ CPS
Thoroughness	▪ DCT/Earthworm Test ▪ CM3, Mental Focus	▪ Inquiry labs ▪ Science Fair Project
Skill	▪ CM3, Learning Orientation	▪ Suchman Inquiry Activities
Clarity	▪ CM3, Cognitive Integrity ▪ CM3, Scholarly Rigor	▪ CPS

Description and Justification of the Analyses

The data collected were quantitative in nature. For the first research question, a multivariate analysis of variance (MANOVA) was implemented and interval data were analyzed to determine if there was a difference in student critical thinking, science process skills, and creative thinking between those students taught by inquiry instruction or direct instruction. All assumptions were checked for the statistic and mean differences between groups were analyzed for all dependent variables. There were five scales associated with critical thinking; one overall score for science process skills; and one score for creativity (only the overall creativity index was used). Therefore, seven dependent variables were examined in the MANOVA. Wilk's Lambda of the independent variable was analyzed and the significance level was established to examine differences on the variate across groups. Partial eta squared was used to explain the percentage of the variance between groups in all dependent variables.

For the second research question, a multiple linear regression (Meyers, Gamst, & Guarino, 2006) was used to determine if the variables of critical thinking, science process skills, creativity, and program type predicted science fair achievement total scores, the criterion variable. All assumptions were checked for this statistic before data were analyzed. Based on the recommendation of Meyers, Gamst, and Guarino (2006), a Bonferronni adjustment was used since the same data were used for each research question in the study. The alpha value was set at .025, by dividing the initial alpha level of .05 by the two research questions.

Ethics Statement

Permission to participate in this research was sought from the school district's superintendent, principal, and all participating teachers. This research was approved by the Institutional Review Board of Western Connecticut State University. To assure confidentiality, each participant was assigned a coded identification number. No names of subjects, schools or districts were used to report the findings of the study. See Appendices J-N for the letters of consent for each of those who participated in this study.

CHAPTER FOUR:

ANALYSIS OF THE DATA AND AN EXPLANATION OF THE FINDINGS

The purpose of this study was to test the effects of an inquiry-based science program on science process skills, creativity, and critical thinking of middle school students. In addition, the definitive goal was to investigate the quality of science fair projects after implementing creative problem-solving strategies in science classes. The specific research questions and hypotheses addressed were:

1. Is there a significant difference in critical thinking skills, science process skills and creativity of middle school science students who participate in an inquiry-based program as compared to students who participate in a science program employing direct instruction?

   Directional hypothesis: Middle school science students who participate in an inquiry-based program will score significantly higher in critical thinking skills, science process skills and creativity as compared to those students who participate in a science program employing direct instruction.

2. To what extent and in what manner do critical thinking skills, science process skills, creativity, and program type predict science fair achievement?

   Directional hypothesis: Critical thinking skills, science process skills, creativity, and program type will predict science fair achievement.

The results are presented in five sections: (a) types of data, (b) screening of data, (c) analysis of the findings of research question one, (d) analysis of the findings of research question two, and (e) chapter summary.

Types of Data

The data analysis incorporated the student results from the *California Measure of Mental Motivation (CM3),* the *Diet Cola Test (DCT),* the *Earthworm Test,* the *Torrance Test of Creative Thinking (TTCT)*, and the *Connecticut Science Fair (CSF) Rubric*. The *CM3* produced the following five scales: (a) Mental Focus, (b) Learning Orientation, (c) Creative Problem Solving, (d) Cognitive Integrity, and (e) Scholarly Rigor. Interval level data were collected for each of these instruments for the pretests and posttests. The pretest data were analyzed for each of these *CM3* subscales, in addition to the *DCT*, and the *TTCT* Figural, Form A. Posttest data were collected and analyzed for each of the *CM3* subscales, the *Earthworm Test*, and the *TTCT* Figural, Form B. Also, science fair achievement data were analyzed based on the use of the *CSF Rubric.*

Data Screening Process

Visual inspection. Once the data were collected, a confirmation procedure was utilized in order to check for correct numerical codes for all values (Meyers, Gamst, & Guarino, 2006). This procedure verified that each case for each variable entered represented a numerical number. Data screening continued with the completion of a visual inspection. Once the data were organized in a spreadsheet, they were transferred to a statistics software program (SPSS, 1999) and saved. During the visual inspection, the researcher examined all data for missing values. There were two missing values in the data set. The researcher went back to the assessments and viewed the hard copy of the scoring, entering the missing values.

Multivariate outliers. After the data were visually inspected and screened, tests were run to detect outliers. An extreme values test using SPSS was run to detect outliers (Meyers, Gamst, & Guarino, 2006). Based on the recommendation of Hair, Anderson, Tatham, and Black (1998), outliers were removed for the pretest and outliers were removed from the posttest data, as the values that were outside of two standard deviations from the mean, or z scores of $\pm$2.0. In addition, as a means for checking and further screening, box plots and extreme values for each variable were examined.

Specifically, the eight values that were removed from the pretest data occurred in the *TTCT* and were case numbers: 4, 29, 61, 103, 116, 133, 171, and 227. All values were $\pm$2.0 standard deviations from the mean. Of these eight values, four were from the inquiry instruction group and four values were part of the direct instruction group. The direct instruction group accounted for four of the five highest scores, and the inquiry group accounted for the three lowest scores. This procedure cleaned the data, and allowed for the groups to be equal across all variables.

In addition, the five outliers from the posttest data were from the *TTCT* and included case numbers: 4, 23, 30, 32, and 61. These outliers fell in the range outside of two standard deviations, and were the five lowest scores in this analysis. Each of these five scores belonged to students in the inquiry group. As a result of these procedures, the total sample size went from 229 (inquiry instruction group n = 113; direct instruction group n = 116) to 224 (inquiry instruction group n = 108; direct instruction group n = 116).

Descriptive statistics of pretest data. As a result of the removal of the outliers, descriptive statistics were analyzed for the adjusted pretest data. Results are presented in Table 15, which describes the mean and standard deviation of each dependent variable across both the inquiry and direct instruction groups.

Table 15

Descriptive Statistics for Pretests of Independent Variables with Respect to Each Dependent Variable

Dependent Variable	Type of Instruction	Mean	Standard Deviation	*n*
Diet Cola Test	Inquiry	4.25	2.091	109
	Direct	4.70	2.460	112
	Total	4.48	2.291	221
TTCT Figural, Form A	Inquiry	86.20	9.625	109
	Direct	87.33	8.899	112
	Total	86.77	9.261	221
CM3 Mental Focus	Inquiry	28.92	8.436	109
	Direct	28.52	7.738	112
	Total	28.71	8.074	221
CM3 Learning Orientation	Inquiry	31.24	7.580	109
	Direct	31.04	7.749	112
	Total	31.14	7.650	221
CM3 Creative Problem Solving	Inquiry	29.40	7.861	109
	Direct	29.06	6.966	112
	Total	29.23	7.406	221

Table 15 (continued)

Descriptive Statistics for Pretests of Independent Variables with Respect to Each Dependent Variable

Dependent Variable	Type of Instruction	Mean	Standard Deviation	*n*
CM3 Cognitive Integrity	Inquiry	31.79	7.292	109
	Direct	31.14	7.263	112
	Total	31.46	7.268	221
CM3 Scholarly Rigor	Inquiry	27.78	6.145	109
	Direct	28.27	6.034	112
	Total	28.03	6.080	221

Individual *t*-tests were conducted to examine initial differences between groups across all dependent variables with respect to the pretest data. For all pretest scores, there was no significant difference between the direct instruction group and the inquiry instruction group for the *Diet Cola Test*, the *TTCT*, Figural A, and the subscales of the *CM3* (Mental Focus, Learning Orientation, Creative Problem-solving, Cognitive Integrity, and Scholarly Rigor).

Research Question One Data Analysis

Assumptions for research question one. Once the outliers were removed as explained earlier, and the data were adjusted, assumptions were checked. Following the recommendation of Meyers, Gamst, and Guarino (2006), the assumptions of normality, linearity, and homoscedasticity were investigated before moving forward with the data analysis.

Normality. The shape and distribution of variables should relate to a normal distribution, or resemble a bell-shaped curve. For this assumption, the skewness and kurtosis for each variable were assessed. Since all values were within the +1.0 to -1.0 range, the data were acceptable for the normality assumption (Meyers, Gamst, & Guarino, 2006). Table 16 displays that this assumption has been satisfied.

Table 16

Descriptive Statistics for Posttests of Independent Variables with Respect to Each Dependent Variable

Dependent Variable	Type of Instruction	Mean	Standard Deviation	Skewness	Kurtosis
The Earthworm Test	Inquiry	5.90	2.395	.364	-.686
	Direct	4.74	2.389	.752	.108
	Total	5.30	2.456	.518	-.424
TTCT Figural, Form B	Inquiry	86.75	8.538	.264	-.044
	Direct	88.68	8.446	.122	-.282
	Total	87.75	8.526	.183	-.216
CM3 Mental Focus	Inquiry	30.28	8.559	.225	-.278
	Direct	28.29	8.225	.168	-.351
	Total	29.25	8.427	.213	-.284
CM3 Learning Orientation	Inquiry	33.22	7.674	.185	-.368
	Direct	31.41	8.358	.188	-.509
	Total	32.28	8.069	.162	-.491
CM3 Creative Problem Solving	Inquiry	31.22	8.426	.075	-.251
	Direct	29.44	8.760	.019	.035
	Total	30.30	8.628	.030	-.072

Note. Descriptive statistics based upon n = 224.

Table 16 (continued)

Descriptive Statistics for Posttests of Independent Variables with Respect to Each Dependent Variable

Dependent Variable	Type of Instruction	Mean	Standard Deviation	Skewness	Kurtosis
CM3 Cognitive Integrity	Inquiry	33.40	7.590	.247	-.124
	Direct	30.85	8.533	-.232	.236
	Total	32.08	8.174	-.253	.097
CM3 Scholarly Rigor	Inquiry	29.40	7.472	-.122	.777
	Direct	28.37	7.129	-.352	.338
	Total	28.87	7.298	-.189	.547

Note. Descriptive statistics based upon n = 224.

Linearity. By visually inspecting scatter plot graphs and histograms across all variables, no curvilinear relationships were observed among all dependent variables (Meyers, Gamst, & Guarino, 2006).

Homoscedasticity. Since more than one dependent variable was used in this statistical analysis, a Box's Test of Equality of Covariance Matrices was conducted in order to test homoscedasticity (Meyers, Gamst, & Guarino, 2006). The Box's Test of Equality of Covariance Matrices was not significant (*Box's M* = 25.250, p = .660), as seen in Table 17, demonstrating that the observed covariance matrices of the dependent variables were equal across the groups. The researcher proceeded with further analysis since the assumption of homoscedasticity was not violated according to Stevens (2002).

Table 17

Box's Test of Equality of Covariance Matrices

Box's M	25.318
F	.874
*df*1	28
*df*2	169911.216
p	.656

Equal variances across groups. The Levene's Test of Error Variances checks for homogeneity of variance violations for each dependent variable. After analyzing the data, equal variances were assumed across groups because results were not statistically significant at the $p < .05$ level. See Table 18 for the values for the Levene's Test for each dependent variable.

Table 18

Levene's Test of Equality of Error Variances for Posttests

	F	*df1*	*df2*	*p*
The Earthworm Test	.137	1	222	.711
TTCT Figural, Form B	.014	1	222	.905
CM3 Mental Focus	.000	1	222	.982
CM3 Learning Orientation	.829	1	222	.364
CM3 Creative Problem Solving	.001	1	222	.972
CM3 Cognitive Integrity	.865	1	222	.353
CM3 Scholarly Rigor	.013	1	222	.908

Analysis of data for research question one. The data analysis was conducted to test the effects of an inquiry learning program. A multivariate analysis of variance (MANOVA) was conducted using seven dependent variables included in research question one: science process skills as measured by the *Earthworm Test*, creativity as indicated by the *TTCT*, Form B, and five areas of critical thinking as measured by the *CM3*. The independent variable was program type, with two levels. Inquiry instruction served as the treatment and direct instruction was employed with the comparison group.

Effects of inquiry on the dependent variables. A Wilk's Lambda (Meyers, Gamst, & Guarino, 2006) was performed on the seven dependent variables. There was a statistically significant difference, $F(7, 216) = 2.910$, $p < .025$, between the means of the comparison and treatment groups. Table 19 represents outcomes from the MANOVA. Since the overall Wilk's Lambda was significant ($p = .006$), the directional hypothesis was accepted.

Table 19

Multivariate Tests for Research Question One

Effect		Value	*F*	Hypothesis *df*	Error *df*	*p*	Partial Eta Squared
Intercept	Wilks' Lambda	.008	3903.682	7.000	216.000	.000	.992
Group	Wilks' Lambda	.914	2.910	7.000	216.000	.006*	.086

*$p < .025$

Each dependent variable was then analyzed using the Tests of Between-Subjects Effects to determine differences between the two levels of the independent variable (inquiry instruction and direct instruction). Group differences were significant for the *Earthworm Test* of science process skills ($p < .001$) and the Cognitive Integrity subscale of the *CM3* ($p = .02$). Refer to Table 20 for a display of the differences between groups.

Table 20

Tests of Between-Subjects Effects for Posttests

Dependent Variable	Type III Sum of Squares	Mean Square	*F*	*p*	Partial Eta Squared
The Earthworm Test	74.839	74.839	13.081	.000***	.056
TTCT Figural, Form B	208.552	208.552	2.893	.090	.013
CM3					
Mental Focus	220.299	220.299	3.131	.078	.014
Learning Orientation	184.658	184.658	2.860	.092	.013
Creative Problem Solving	177.716	.716	2.403	.123	.011
Cognitive Integrity	362.165	362.165	.531	.020*	.024
Scholarly Rigor	59.042	59.042	1.109	.293	.005

*$p < .025$, **$p < .01$, ***$p < .001$

Group means revealed that students in the treatment group had significantly higher scores, $F(1, 222) = 13.081$, $p < .001$ on the science process skills assessment, The *Earthworm Test* ($M = 5.90$, $SD = 2.395$) than the comparison group ($M = 4.74$, $SD = 2.389$). Those in the treatment group also scored significantly higher, $F(1, 222) = 5.531$, $p = .02$ on the Cognitive Integrity subscale of the *CM3* ($M = 33.40$, $SD = 7.590$) than students in the comparison group ($M = 30.85$, $SD = 8.533$). Although not significant in nature, it is also important to note that for four of the remaining five dependent variables, students had higher scores when they participated in the inquiry treatment group compared to those in the comparison group. These dependent variables include Mental Focus, Learning Orientation, Creative Problem Solving, and Scholarly Rigor. Table 16 displays the group means for each dependent variable measured in this research question.

Research Question Two Data Analysis

According to research question two, a multiple linear regression (Meyers, Gamst, & Guarino, 2006) was used to determine if the predictor variables of science process skills, creativity, the five areas of critical thinking, and program type predicted science fair achievement scores, the criterion variable.

Multivariate outliers. As described earlier, an extreme values test using SPSS was conducted to detect outliers (Meyers, Gamst, & Guarino, 2006). Based on the recommendation of Hair, Anderson, Tatham, and Black (1998), outliers were removed as the values that were outside of two standard deviations from the mean, or z scores of ± 2.0.

A total of five outliers were removed from the TTCT posttest data, case numbers: 4, 23, 30, 32, and 61. These outliers fell in the range outside of two standard deviations, and were the five lowest scores in this analysis. Each of these five scores belonged to students in the inquiry group.

Assumptions for research question two. Once the outliers were removed, the assumptions were checked. Following the recommendation of Meyers, Gamst, and Guarino (2006), the assumptions of normality, linearity, and homoscedasticity were investigated before moving forward with the regression analysis.

Normality. The shape and distribution of variables should relate to a normal distribution, or resemble a bell-shaped curve. For this assumption, the skewness and kurtosis were assessed. Since all values were within the +1.0 to -1.0 range, the data were acceptable for the normality assumption (Meyers, Gamst, & Guarino, 2006). This was verified by visual inspection. Table 16 displays that this assumption has been satisfied.

Linearity. By visually inspecting scatter plot graphs across all variables, no curvilinear relationships were observed among any of the dependent variables (Meyers, Gamst, & Guarino, 2006). Likewise, histograms of all dependent variables revealed no curvilinear relationships as well.

Homoscedasticity. Equal levels of variability across the range of independent variables were observed when analyzing scatter plot graphs, as well as histograms. There was not a funnel-shaped residual output observed, and dispersion of the errors of prediction were equal for all predicted dependent variable scores (Meyers, Gamst, & Guarino, 2006). The assumption of homoscedasticity was not violated according to Stevens (2002).

Correlations. A correlation matrix was analyzed next in the regression based on the recommendation of Meyers, Gamst, and Guarino (2006). The interrelationships of all variables were examined. As expected, all subscales of the *CM3* were moderately to strongly correlated with each other ($p < .001$). There was a low positive relationship between all subscales of the *CM3* and the *Earthworm Test* ($p < .001$). There was little to no correlation between scores from the *TTCT* and any of the other predictor variables in this analysis. Exact values are listed in Table 21. Lastly, it is important to note that there was a low positive relationship between science fair scores and science process skills ($p < .001$), Mental Focus ($p < .05$), and Cognitive Integrity ($p < .05$). Since most of the variables are correlated with each other at a significant level, but are not too highly correlated, this assumption is satisfied (Meyers, Gamst, & Guarino, 2006). See Table 21 for the correlation matrix for all variables in the regression analysis.

Table 21

Correlation Matrix of the Variables in Regression Analysis

	1.	2.	3.	4.	5.	6.	7.
1. The Earthworm Test							
2. TTCT Figural, Form B	.121						
3. CM3 Mental Focus	.302***	.057					
4. CM3 Learning Orientation	.330***	.027	.521***				
5. CM3 Creative Problem Solving	.323***	.118	.577***	.736***			
6. CM3 Cognitive Integrity	.378***	.045	.499***	.493***	.435***		
7. CM3 Scholarly Rigor	.351***	.129	.562***	.739***	.726***	.516***	
8. Science Fair Achievement	.271***	.037	.173***	.062	.080	.157*	.113

*Correlation is significant at the .05 level (2-tailed)

**Correlation is significant at the .01 level (2-tailed)

***Correlation is significant at the .001 level (2-tailed)

Multicollinearity considerations. Based on the recommendation of Meyers, Gamst, and Guarino (2006), the collinearity statistics output were examined before reporting the significant findings of predictors and of the models. Model one included the following predictors: the *Earthworm Test*, *TTCT*, Figural, Form B, *CM3* Mental Focus, *CM3* Learning Orientation, *CM3* Creative Problem-solving, *CM3* Cognitive Integrity, and *CM3* Scholarly Rigor. The model two block added program type. Tolerance values were analyzed to be greater than .01, therefore multicollinearity was not a problem. Also, when examining the variance inflation factor (VIF) statistic, all values were less than 10, verifying the absence of multicollinearity. See Table 22 for a list of tolerance and VIF statistics for each of the variables.

Table 22

Collinearity Statistics of Posttests

Model	Predictor Variables	Tolerance	VIF
1	The Earthworm Test	.825	1.212
	TTCT Figural, Form B	.953	1.050
	CM3 Mental Focus	.610	1.641
	CM3 Learning Orientation	.385	2.596
	CM3 Creative Problem Solving	.371	2.694
	CM3 Cognitive Integrity	.582	1.717
	CM3 Scholarly Rigor	.373	2.678
2	The Earthworm Test	.791	1.264
	TTCT Figural, Form B	.928	1.077
	CM3 Mental Focus	.609	1.641
	CM3 Learning Orientation	.384	2.603
	CM3 Creative Problem Solving	.368	2.714
	CM3 Cognitive Integrity	.577	1.734
	CM3 Scholarly Rigor	.367	2.726
	Program Type	.888	1.126

Relationship of predictor variables on science fair achievement. Once the multiple regression considerations were addressed, data were analyzed to determine the effects of the predictor variables (science process skills, creativity, critical thinking and program type) on the criterion variable (science fair achievement). Blocks of variables were entered as predictors. The first block consisted of science process skills, creativity, and the five subscales of the *CM3*. The second block consisted of the predictor, program type. Variables were entered in this sequence based on the recommendation of Meyers, Gamst, and Guarino (2006). By entering program type as the predictor variable in block two, and the other variables together in block one, the significance of program type could be determined after accounting for the variance of all other variables.

The first model for the output represents the first block. It is used to determine the manner and degree to which science process skills, creativity, and critical thinking were significant predictors of science fair achievement. Multiple *R* was significant for the first block, $F(7, 171) = 2.420$, $p < .025$. Within this model, science process skills contributed significantly to the prediction of science fair achievement ($p < .025$), while none of the critical thinking skills were significant predictors, nor was the average score for the *TTCT*, Figural, Form B. Science process skills, creativity, and critical thinking were significant predictors of science fair achievement, predicting 9.0% of the variation in science fair project scores. See Table 23 and Table 24 for a summary of the data established for model one. Refer to Table 25 for the coefficients with respect to this model.

Multiple *R* was significant for the second block, $F(1, 170) = 4.212$, $p < .001$. Within this model, science process skills ($p < .025$) and program type ($p < .001$) contributed significantly to the prediction of science fair achievement. Program type contributed significantly to the prediction of science fair achievement scores above and beyond the other predictor variables associated with model one. Model two resulted in a total explanation of 16.5% of the variance in science fair project scores. Since the R-square change from model one to model two was 7.5% resulting in a significant *F* change of $p < .001$, it can be concluded that program type was a major predictor of science fair achievement. Since the ANOVA for model one ($p < .025$) and model two ($p < .001$) were significant, the directional hypothesis was accepted. See Table 23 and Table 24 for a summary of the data established for model two. Refer to Table 26 for the coefficients with respect to this model.

Table 23

Model Summary for Research Question Two

Model	*R*	*R* square	Adjusted *R* square	Standard Error of the Estimate	*R* square change	*F* change	Sig *F* change
1	.300	.090	.053	14.413	.090	2.420	.022*
2	.407	.165	.126	13.845	.075	15.340	.000***

**p* < .025, ***p* < .01, ****p* < .001

Table 24

ANOVA for Research Question Two

Model		Sum of Squares	*df*	Mean Square	*F*	*p*
1	Regression	3518.568	7	502.653	2.420	.022*
	Residual	35524.438	171	207.745		
	Total	39043.005	178			
2	Regression	6458.842	8	807.355	4.212	.000***
	Residual	32584.163	170	191.672		
	Total	39043.005	178			

p < .025, **p* < .01, ***p* < .001

Table 25

Coefficients for Science Fair Achievement Scores for Model One

Posttest Predictor Variables	Unstandardized Coefficients B	Unstandardized Coefficients Standard Error	Standardized Coefficients Beta	*t*	*p*
(Constant)	70.005	12.244		5.718	.000
The Earthworm Test	1.513	.498	.244	3.036	.003*
TTCT Figural, Form B	-.004	.129	-.002	-.031	.975
CM3 Mental Focus	.250	.167	.140	1.500	.135
CM3 Learning Orientation	-.142	.223	-.075	-.635	.527
CM3 Creative Problem Solving	-.069	.207	-.040	-.332	.740
CM3 Cognitive Integrity	.058	.174	.032	.333	.739
CM3 Scholarly Rigor	.050	.255	.024	.198	.843

*$p < .025$

Table 26

Coefficients for Science Fair Achievement Scores for Model Two

Posttest Predictor Variables	Unstandardized Coefficients B	Unstandardized Coefficients Standard Error	Standardized Coefficients Beta	*t*	*p*
(Constant)	62.586	11.912		5.254	.000
The Earthworm Test	1.123	.489	.181	2.297	.023*
TTCT Figural, Form B	.075	.126	.043	.596	.552
CM3 Mental Focus	.255	.160	.143	1.589	.114
CM3 Learning Orientation	-.185	.215	-.098	-.863	.389
CM3 Creative Problem Solving	-.136	.200	-.079	-.683	.496
CM3 Cognitive Integrity	-.006	.167	-.003	-.035	.972
CM3 Scholarly Rigor	.179	.247	.084	.725	.469
Program Type	8.611	2.199	.291	3.917	.000***

*$p < .025$, **$p < .01$, ***$p < .001$

Science fair achievement based on group. As a follow up, when examining science fair achievement scores between groups using *t*-test analysis, the inquiry instruction group scored significantly higher (M = 85.59, SD = 10.575) than the direct instruction group (M = 76.84, SD = 16.729), $p < .001$. See Table 27 for statistics for science fair achievement comparing the groups.

Table 27

Mean Differences for Science Fair Achievement Scores by Group

Program Type	*n*	Mean	Standard Deviation	Standard Error Mean
Inquiry Instruction	90	85.59	10.575	1.115
Direct Instruction	94	76.84	16.729	1.725

Chapter Summary

Chapter Four presents all data related to the two research questions in this study. The data represents the effects of an inquiry-based science program on science process skills, creativity, and critical thinking of middle school students through the use of a MANOVA. Group differences were significant for science process skills as measured by the *Earthworm Test* ($p < .001$) and the Cognitive Integrity subscale of the *CM3* ($p = .02$). In addition, variables contributing to an explanation of science fair project scores were examined were examined through regression analysis. The major predictors were science process skills ($p < .025$) and type of instructional program ($p < .001$), with students in the inquiry program achieving higher scores on their science fair projects than those in the direct instruction science classes.

CHAPTER FIVE: SUMMARY AND CONCLUSIONS

Chapter Five represents a discussion of the findings of the study as related to the literature and an overall summary of the research. The *Summary* and *Findings* section gives an overview of the entire study and provides a review of the results from the statistical analysis of the effect of inquiry instruction on science process skills, creative thinking, critical thinking, and science fair achievement. The Discussion section, titled, *Comparison and Contrast of Findings Related to the Literature Review*, relates the findings to the constructs presented in Chapter Two. *Implications for Education* provides overarching applications for educators. The *Limitations* section provides threats to the study and how these threats were best controlled. Propositions for future studies based on the findings of this research are presented in the section, *Implications for Future Research*.

Summary and Review of the Findings

The rationale of this study was to understand the impact of an inquiry-based science program on science process skills, creative ability, and critical thinking. In addition, the ultimate goal was to investigate the quality of science fair projects after implementing creative problem-solving and critical thinking strategies in science classes. A directional hypothesis was made, favoring inquiry instruction. This project was based on state and national science standards and was intended to develop inquiry skills through the implementation of specific inquiry-related strategies.

A sample of convenience (n = 229) was drawn from a population of middle school students (N = 690). Four science teachers at the seventh and eighth grade levels participated in the study. Two of these teacher participants, one per grade level, were randomly assigned to an inquiry program in science that was implemented over a 19-week period. The remaining teachers taught their science classes using a traditional, direct instructional approach.

Teachers in the treatment group used components of the Creative Problem-solving (CPS) model (Treffinger & Isaksen, 2005), as well as the Suchman inquiry model (Suchman, 1968) in earth science (Grade 8) and biology (Grade 7) classes. Strategies from the CPS model allowed for the brainstorming of science fair topic ideas. Students practiced how to conduct experiments by participating in inquiry-based labs in their science classes. Student work collected from the activities above, along with reflections in inquiry journals, provided a focus for how students were progressing and provided evidence that teachers in the treatment group used the inquiry program strategies. During weekly meetings with the teachers, the researcher verified how each teacher administered these strategies. The researcher also confirmed the strategies used by teachers in the comparison group. Although students in the direct instruction group were involved in science labs that were similar to those employed in the inquiry group, and they completed science fair projects, it was clear from these regular meetings that strategies used in the inquiry program were not being used in the classes of the comparison group.

Summary of research question one. The effect of the independent variable, science program, was examined with respect to the dependent variables: science process skills, critical thinking, and creative thinking. Data were analyzed to determine if differences existed between students who participated in an inquiry-based science instruction program and those who attended a direct instruction program. The specific research question was: Is there a significant difference in critical thinking skills, science process skills and creativity of middle school science students participating in an inquiry-based program as compared to students who participate in a science program employing direct instruction?

Data were collected using three instruments to measure all seven dependent variables. Critical thinking was measured through five subscales of the *California Measure of Mental Motivation* (Giancarlo, 2010) for the pretest and posttest. Pretest scores for science process skills were assessed using the *Diet Cola Test* (Fowler, 1990) and posttest scores were gathered using The *Earthworm Test* (Adams & Callahan, 1995). Creativity was measured using the creativity index of the *Torrance Test of Creative Thinking (TTCT)* Figural, Form A for the pretest and Figural, Form B for the posttest (Torrance, 1966).

For this research question, a multivariate analysis of variance (Meyers, Gamst, & Guarino, 2006) was conducted to determine if participation in either instructional group affected science process skills, critical thinking, and creative thinking.

Findings for research question one. A multivariate analysis of variance (MANOVA) was conducted to examine the directional hypothesis that students in the inquiry group would have significantly higher scores than those in the direct instruction group across the seven dependent variables: science process skills and creativity, in addition to the five subscales of the *California Measure of Mental Motivation* (*CM3*): Mental Focus, Learning Orientation, Creative Problem-solving, Cognitive Integrity, and Scholarly Rigor.

All data were cleaned and assumptions were checked. As a result of conducting the MANOVA, the groups were significantly different (p = .006). The directional hypothesis was accepted. When examining further, follow up testing suggested that significance was attained for two of the seven dependent variables: science process skills (M = 5.90, SD =

2.395, $p < .001$) and Cognitive Integrity ($M = 33.40$, $SD = 7.590$, $p = .02$). The partial eta-squared effect size was 5.6% for science process skills and 2.4% for Cognitive Integrity.

Despite the outcome of only two variables demonstrating significance in the MANOVA, it is important to note that the mean values for the treatment group were higher than those of the comparison group for all dependent variables except one (*TTCT* Figural, Form B average scores, where there were no differences). This is a clear indication that the program was successful in raising scores in the areas of science process and critical thinking skills.

Summary of research question two. The extent and manner in which science process skills, critical thinking, creativity, and participation in a science inquiry program predicted science fair achievement was examined. Data were analyzed to determine which variables predicted science fair achievement. The second research question was: To what extent and in what manner do critical thinking skills, science process skills, creativity, and program type predict science fair achievement?

Data were collected and analyzed using posttest scores from four instruments. Critical thinking was measured through five subscales of the *California Measure of Mental Motivation* (Giancarlo, 2010). Science process skills were measured using the *Earthworm Test* (Adams & Callahan, 1995). The *Torrance Test of Creative Thinking*, Figural, Form B (Torrance, 1966) represented creative abilities. Science fair achievement was estimated using ratings from the *Connecticut Science Fair Rubric* (CSF, 2006).

For this research question, a multiple linear regression (Meyers, Gamst, & Guarino, 2006) was used to determine if the posttest variables listed above predicted science fair achievement scores. Data were analyzed for each of two models in the regression analysis.

Findings for research question two. A hierarchical multiple linear regression was conducted to test the hypothesis that the predictor variables of critical thinking, science process skills, creativity (block 1), and program type (block 2) predicted science fair achievement scores, the criterion variable.

In the regression analysis, it was found that a model containing the predictor variables of science process skills, creativity, and critical thinking, was a significant predictor of science fair achievement. In terms of coefficients, science process skills contributed significantly to the prediction of science fair achievement ($p < .025$). Model two explained that program type contributed significantly to the prediction of science fair achievement scores above and beyond the other predictor variables associated with model one ($p < .001$). Overall, science process skills ($p < .025$) and program type ($p < .001$) contributed significantly to the prediction of science fair achievement. The directional hypothesis was accepted.

One most important finding was the effect of program on science fair achievement. Science fair scores were significantly higher ($p < .001$) for the inquiry instruction group as compared those of the direct instruction group. It appears that the components of the program contributed to the overall impact in science fair achievement.

Follow-up analyses. Since one focus of the research was to assist in the developing ideas for science fair projects, the researcher decided to examine each subscale of the *TTCT* posttest scores to investigate if any of the particular constructs were significantly different for the treatment and comparison groups. This additional analysis included score for each of the *TTCT* subscales: Fluency, Originality, Elaboration, Abstractness of Titles, and Resistance to Premature Closure. By examining a MANOVA where each subscale was a dependent variable and the independent variable of program type was used, there was a statistically significant difference in fluency scores in favor of the inquiry group ($p < .05$). This result lends support to using CPS as a strategy for increasing fluency of ideas. See Appendix I for these data related to the *TTCT* subscales.

Comparison and Contrast of Findings Related to the Literature Review

The Review of the Literature presented in Chapter Two suggested that inquiry has historical roots based on the constructs of John Dewey, Jerome Bruner, and others who have included similar components in their meaning of inquiry (Bell, Smetana, & Binns, 2005; Colburn, 2000; Dunkhase, 2003; Herron, 1971; Martin-Hansen, 2002; NRC, 2000; Perkins, 1991; Schön, 1992; Schwab, 1962). Despite the numerous publications by historical theorists and researchers, there is a scarce amount of literature surrounding the effects of inquiry on critical thinking, creative thinking, and science fair achievement of middle school students.

Constructivist theory in relation to inquiry instruction. The views proposed in Chapter Two describe inquiry learning as a result of a constructivist approach in which students' lab experiences were more valuable than the simple recall of information. The basis for the present day process of inquiry is embedded in the work of John Dewey. Dewey (1938) described the relationship between education and the processes of actual experience.

The theoretical basis for the inquiry program implemented in this study was founded on the notion that manipulation of science content provides experiences for students to construct meaning. Students were exposed to a variety of inquiry activities that were guided in nature. Activities used in this study are situated at the guided and open inquiry levels of the continuum according to the researchers in Chapter 2 (Bell, Smetana, & Binns, 2005; Colburn, 2000; Dunkhase, 2003; Herron, 1971; Martin-Hansen, 2002). More specifically, the Suchman inquiry activities and processes involved in CPS allowed students to think critically through meaningful experiences.

Bruner (1961) described constructivism as a knowledge-getting process. This was his basis for problem-solving. Bruner's model connected to this study in that students were exposed to guided inquiry supported by scaffolded, content-driven activities. By implementing the CPS process to select science fair topics, students were able to tap into components associated with open inquiry, thereby extending their critical thinking skills. Perkins (1991) agreed that these constructivist processes allow learners to create and elaborate on mental structure to produce ideas until a satisfactory thought emerged.

The process of inquiry in science. Inquiry as a process promotes learning as assessed by the variables utilized in this study, science process skills, creativity, and critical thinking skills. The science process skills associated with the *Diet Cola Test* (Fowler, 1990) and its alternative form the *Earthworm Test* (Adams & Callahan, 1995) related distinctly to the expected performances of the state of Connecticut's science standards (CSDE, 2004). Some of these skills included, but were not limited to questioning, hypothesizing, designing procedures, and drawing conclusions. Furthermore, these were the types of skills targeted in the treatment of guided inquiry instruction.

Despite the limited research in the area of inquiry's effect on science process skills, significant results have been associated with the use of these process skills in inquiry instruction related to middle school students. Brickman, Gormally, Armstrong, and Heller (2009) suggested that students who received inquiry instruction showed significant gains in science process skills. Mattheis and Nakayama (1988) proposed that lab-centered inquiry instruction had significant effects on the skills associated with science processes. Lastly, Bilgin (2006) utilized an inquiry approach that included hands-on activities through the use of cooperative groups, concluding that this method of instruction developed science process skills. Other studies also verified that inquiry-based instruction had a significant impact on science processes (Blanchard, Southerland, Osborne, Sampson, & Annetta, 2010; Chang & Mao, 1999; Panasan & Nuangchalerm, 2010).

Science process skills provide opportunities for critical thinking. Giancarlo (2010) classified critical thinking according to five subscales of the *CM3* instrument: Mental Focus, Learning Orientation, Creative Problem Solving, Cognitive Integrity, and Scholarly Rigor. In the present study, cognitive integrity scores were significantly higher for the students in inquiry-oriented science classrooms.

Giancarlo (2010) described individuals with high levels of cognitive integrity as those who display the following characteristics: motivation, open-mindedness, and truth-seeking. Giancarlo also suggested that students use thinking skills when they are comfortable with challenges. Cognitive Integrity played a role in the treatment as students were exposed to activities that were motivating in nature. The Suchman inquiry lessons relate to the truth-seeking and open-minded characteristics described by Giancarlo (2010) in that these activities require students to think critically, ask questions, and form solutions based on the information they gather in the process. The CPS activities relate to cognitive integrity in that divergent thinking is stimulated through the brainstorming of more original and creative science fair project ideas.

Hawkins and Pea (1987) believed that inquiry encompassed higher-order thinking skills in creating a problem, collecting data, and making sense of that information. Suchman inquiry activities in this study, in conjunction with inquiry labs based on the state embedded task assessments, provided a link to each of these processes experienced by the treatment group. These processes stimulated critical thinking according to the Cognitive Integrity subscale of the *CM3*.

Research utilizing the Suchman inquiry model verifies the benefit of inquiry for critical thinking. Alshraideh (2009) found that by fostering inquiry through the use of questioning, critical thinking was promoted.

Although significance was not attained for the average scores for creative thinking in this study, follow-up results showed that the fluency component of the *TTCT* was related to components of the inquiry program. By using CPS for the brainstorming of science fair ideas, creativity was stimulated and students were able to generate many ideas before eventually choosing their final project topic. Delcourt (2008) supports this concept through her work with creative-productive secondary school students.

Science fair achievement. As seen in Chapter Two, there is limited research related to science fair achievement. In fact, no research was found at the middle school level. This study attempted to add to this body of knowledge by implementing an inquiry program based on skills related to the science fair process. More importantly, the goal was to examine a set of variables in terms of the degree to which they predicted science fair achievement.

Pyle (1996) suggested that the science fair process was influenced by motivational factors. Consistent with Pyle's finding, motivational experiences took place through the use of Suchman inquiry activities, inquiry-based labs, and the CPS process. In addition, LaBanca (2008) concluded that the quality of science fair projects was impacted by collaboration, communication, and implementation of problem-finding techniques. The problem-finding features of the Suchman Inquiry model as well as CPS provide these activities for students in the inquiry-related science classrooms.

Implications for Education

Inquiry-based learning has taken on many forms over the years and throughout history, and, will continue to impact future learners. Educators face the demands of standardized testing, but can prosper with the use of inquiry instruction. Longo (2011) stated:

> By using an inquiry approach, educators can spark students' curiosity, increase levels of motivation, inspire creativity, and bring authenticity to learning through real-world lessons. Teachers who implement inquiry learning in this way help to develop lifelong learners. Moreover, because inquiry is central to the NSES and is an important component of most states' science standards, this type of instruction helps students prepare for high-stakes standardized assessments. (p. 14)

This research study addressed the necessity for an inquiry-based science program at the middle school level. Results of this research can assist educators in developing instruction that stimulates students to brainstorm effectively, think critically and creatively, and develop the science process skills needed to understand how to conduct scientific investigations. This type of instruction can produce more authentic and meaningful products that include labs and science fair projects.

Despite the benefits of direct instruction, exclusive use of this model forces students to follow a scripted procedure to complete science investigations. Through the use of a guided inquiry approach, students can explore meaningful content by asking questions, forming hypotheses, and discovering knowledge using limited assistance. When providing a framework that supports critical thinking, student-generated questions follow. Developing a plan to improve questioning skills is indeed a key variable in student involvement in inquiry (Shore, Aulls, & Delcourt, 2008).

Inquiry programs that contain opportunities for critical thinking and creativity stimulate student interest by relating the content to every day experiences "Real-world connections to the curriculum enhance the use of inquiry learning in the classroom. Further thoughts and ideas arise when students share their findings and discuss their personal connections" (Longo, 2011, p. 7).

Limitations of the Study

Threats to internal validity. The threats controlled by this design are maturation and statistical regression. The maturation threat is defined as "physical or psychological changes in the research participants" (Gall, Gall & Borg, 2007, p. 385). Statistical regression is "the tendency for research participants whose scores fall at either extreme on a measure to score nearer the mean when the variable is measured the second time" (Gall, Gall & Borg, 2007, p. 385). To address these threats, the researcher administered both a pretest and posttest for both the treatment and comparison groups. Since the researcher could not randomly assign subjects to their groups, there was no true experimental design. This could have led to a threat for group differences being due to maturation. However, cleaning the data and finding no pretest differences, the researcher is confident that maturation and statistical regression to the mean were effectively controlled for through this design.

The identified threats to internal validity of this research are: selection, testing, experimental treatment, and compensatory rivalry by the comparison group. The researcher was aware of these potential threats and developed a system for addressing each of these. By closely monitoring the treatment and comparison groups, these threats were able to be at least partially controlled.

Subject selection presented a threat because there was no random assignment of groups since intact classes were utilized. However, students were from the same school with similar demographics across grade levels. The homogeneity of the subjects' characteristics was a minor control of this potential threat.

Testing presents an issue for researchers. Some students can improve their learning strategies merely by taking the test. To address this threat, the researcher used instruments that have established reliability and validity and employed alternate test forms for two of the instruments. Also, the time between tests (19 weeks) helped control this threat.

Gall, Gall & Borg (2007) described the threat to an experimental treatment: "If the treatment condition is perceived as highly desirable relative to the control condition, members of the control group may seek access to the treatment condition" (p. 387). To address this threat, the researcher made every attempt to oversee that contact was limited between experimental and comparison groups by making weekly visits to the school to discuss teaching practices in the classroom. The researcher did this by examining specific work produced by the students in each group, discussing the delivery of curriculum with each teacher, and following up with teachers on a weekly basis. A potential threat existed in which the comparison group teachers could have provided additional support on science fair projects and that this information was not shared in the check-in meetings. This threat was controlled for as best as possible.

When the comparison group members perceive that they are in competition with the treatment group, they may perform beyond their usual level, leading to the John Henry effect, also called compensatory rivalry by the comparison group. To be sure that the current programs were being implemented, the researcher visited the school for check-in meetings. It was verified that teachers in the comparison group were implementing a direct instruction program, and that this group was not following any of the treatment group's strategies. To further address this threat, initial training was offered for the comparison group after the study, so that all children and teachers obtained the same opportunity to use the strategies implemented by the treatment teachers.

External validity. While the results of one study cannot be generalized to other groups, researchers with students from similar demographics, such as middle school students of a suburban district with predominantly Caucasian students from families with similar incomes, could explore the characteristics of this sample in order to examine the degree to which the results of this study could be applied to other settings.

"The Hawthorne effect refers to any situation in which the experimental conditions are such that the mere fact that individuals are aware of participating in an experiment, are aware of the hypothesis, or receiving special attention improves their performance" (Gall, Gall & Borg, 2007, p. 390). This threat was partially controlled by the researcher's explanation to parents and students that the study was part of the students' educational program and by efforts to limit the amount of attention the study received throughout its implementation. It is also important to note that students at the middle school level often talk in the hallways about their experiences in their classes. This was one aspect that could not be controlled.

Implications for Future Research

Research question one. The purpose of research question one was to examine the effect of participation in an inquiry-based science program on the science process skills, creative thinking, and critical thinking of middle school students. Opportunities exist for future research to address areas of improvement in this study. These could include enriching the treatment with more extensive strategies, adding multiple data collection points, assessing different types of inquiry programs, and collecting data that represents more precise types of creative abilities and behaviors.

Future research is needed to address additional ways to include creativity into guided inquiry. By using CPS more often and in more depth throughout the program, creative outcomes could increase in science classrooms.

A repeated measures analysis could be conducted in order to assess the inquiry program over a longer time frame. By focusing on the inquiry group in a repeated measures design, the researcher could identify specific aspects of the program beneficial to improving science fair achievement.

Extending the levels of the independent variable to include open inquiry, future researchers can differentiate between the types of strategies that are the more successful for the different levels of inquiry. Program type as the independent variable, including three levels: direct instruction, guided inquiry instruction, and open inquiry instruction can provide additional information to pinpoint the effectiveness of the strategies implemented.

Additionally, the isolation of the fluency and originality subscales of the *TTCT* as dependent variables, in addition to science process skills, and the subscales of the *CM3* could lead to interesting research. Brainstorming strategies, used in conjunction with inquiry labs and Suchman-based activities could benefit students in the areas of fluency and originality.

Research question two. Research question two was developed to understand how science process skills, creativity, and critical thinking contributed to the prediction of science fair achievement. Despite the overall success of the inquiry program as indicated by the results of the second research question, future research is needed in the area of science fair achievement. The scarcity in literature prompted this research question. Future studies are required to assess science fair achievement with more CPS instruction for a longer period of time. Utilizing the subscales of the *TTCT*, in conjunction with subscales of the *CM3* and the *Connecticut Science Fair Rubric*, could provide the researcher with other predictors of science fair achievement.

The Creative Problem Solving model provided students with a structured way to organize their ideas for the science fair project. This instructional strategy proposes opportunities for teachers and students to add a component of creativity into their curriculum. Due to time constraints based on the school's timeline for the introduction of the annual science fair, as well as the timing of the onset of this study, the CPS process was conducted by teachers for only one week at the start of the science fair and one week after the science fair. By providing more opportunities for students to use the CPS model, students can benefit in terms of creativity.

Chapter Summary

In conclusion, this study was designed to investigate the impact of an inquiry-based science program on the critical thinking skills, science process skills, creativity, and science fair achievement of middle school students. There is limited empirical research relating specific inquiry-based programs to critical thinking, creativity, and science fair achievement in middle school classrooms. There is a connection to the theoretical construct of constructivism, as the instructional practices utilized in the treatment are supported by research. Significant findings in this study suggest that there is a clear link between guided inquiry and science process skills, and that this type of inquiry instruction benefits science fair achievement. Further research is needed in terms of additional influence of science fair achievement, in addition for the need for inquiry's relationship to creative thinking.

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Appendix A: Professional Development Powerpoint

The toolbox for developing critical and creative thinkers: An Inquiry-based Science Program

Chris Longo, M.S.
Science Department Chair
Bethel High School

Marcy Delcourt, Ph.D.
Coordinator, EdD program,
Instructional Leadership

Planned Agenda December 2, 2010

- 1. Welcome and overview
- 2. Purpose of the study
- 3. Outline of study activities
- 4. Expectations and outcomes
- 5. Why inquiry?
- Break (10 minutes)
- 6. Suchman inquiry model
  7. Longo Suchman example(s) – You try!
- 8. Creative Problem Solving (CPS)
- 9. Demo in 8th grade classroom, D'Amico, block 5 = 11:03 - 11:40
- 10. Debrief in conference room
- Lunch (30 minutes)
- 11. Demo in 7th classroom, Reynolds, block 7 = 12:56 - 1:33
  12. Debrief in conference room
- 13. Q&A and final remarks

Rationale

- Inquiry learning models support direct instruction to promote critical and creative thinking skills.
- Science fair project ideas chosen by middle school students lack creativity.
- State standards are aligned around an inquiry premise.

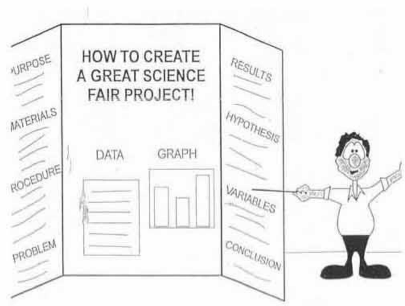


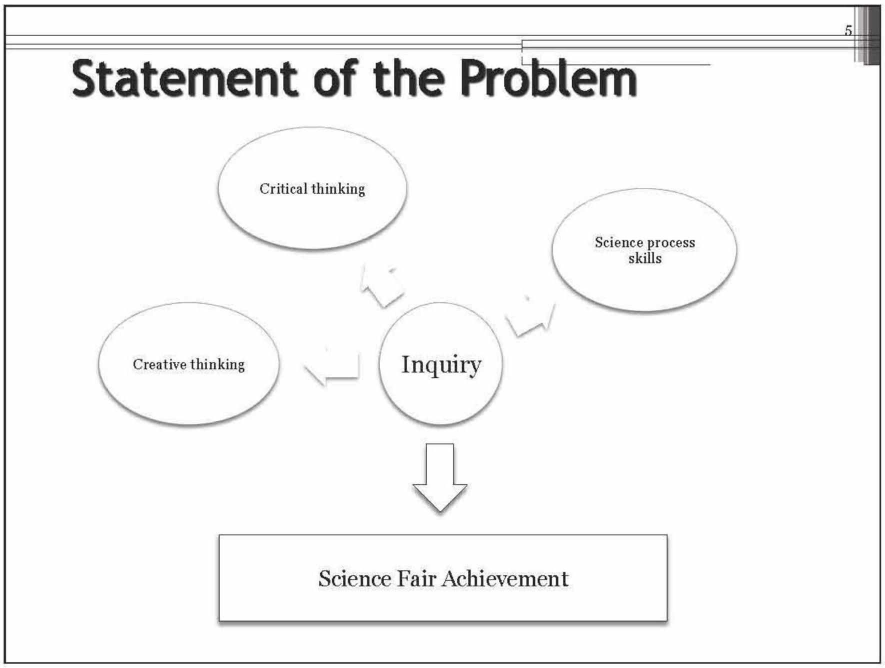
Image taken from:
http://bce.eanes.k12.tx.us/ScienceFair_Current/sciencefairdisplayboard.htm

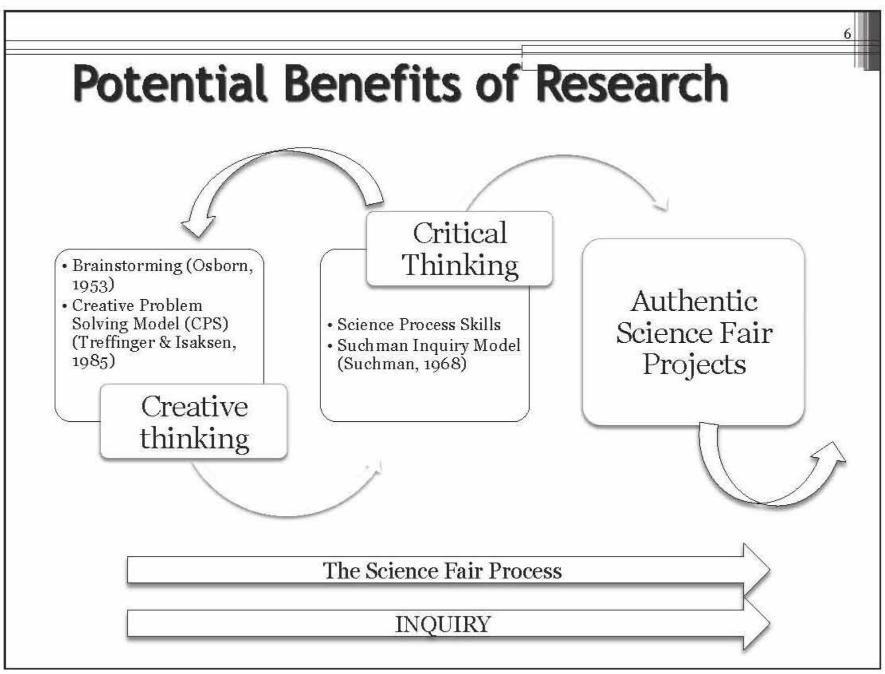
Grades 6-8 Core Scientific Inquiry, Literacy and Numeracy

How is scientific knowledge created and communicated?

Content Standards	Expected Performances	
SCIENTIFIC INQUIRY	C INQ.1	Identify questions that can be answered through scientific investigation.
♦ Scientific inquiry is a thoughtful and coordinated attempt to search out, describe, explain and predict natural phenomena.	C INQ.2	Read, interpret and examine the credibility of scientific claims in different sources of information.
♦ Scientific inquiry progresses through a continuous process of questioning, data collection, analysis and interpretation.	C INQ.3	Design and conduct appropriate types of scientific investigations to answer different questions.
♦ Scientific inquiry requires the sharing of findings and ideas for critical review by colleagues and other scientists.	C INQ.4	Identify independent and dependent variables, and those variables that are kept constant, when designing an experiment.
	C INQ.5	Use appropriate tools and techniques to make observations and gather data.
SCIENTIFIC LITERACY	C INQ.6	Use mathematical operations to analyze and interpret data.
♦ Scientific literacy includes speaking, listening, presenting, interpreting, reading and writing about science.	C INQ.7	Identify and present relationships between variables in appropriate graphs.
♦ Scientific literacy also includes the ability to search for and assess the relevance and credibility of scientific information found in various print and electronic media.	C INQ.8	Draw conclusions and identify sources of error.
	C INQ.9	Provide explanations to investigated problems or questions.
SCIENTIFIC NUMERACY	C INQ.10	Communicate about science in different formats, using relevant science vocabulary, supporting evidence and clear logic.
♦ Scientific numeracy includes the ability to use mathematical operations and procedures to calculate, analyze and present scientific data and ideas.		

(CSDE, 2004)


5
Statement of the Problem
Critical thinking
Science process skills
Creative thinking
Inquiry
Science Fair Achievement


6
Potential Benefits of Research
• Brainstorming (Osborn, 1953)
• Creative Problem Solving Model (CPS) (Treffinger & Isaksen, 1985)
Creative thinking
Critical Thinking
• Science Process Skills
• Suchman Inquiry Model (Suchman, 1968)
Authentic Science Fair Projects
The Science Fair Process
INQUIRY

Connecticut Science Fair Project Rubric

1. Scientific Thought/Engineering Goals (30 points)
   Points are awarded for:

Scientific	Engineering
(1) Evidence of use of scientific method	(1) Identification of clear objectives
(2) Clear statement of a problem	(2) Objective relevant to user needs
(3) Problem is limited and soluble	(3) Solution is - workable, acceptable to user, economically feasible
(4) Evidence of a procedural plan	(4) Solution compatible with potential end product
(5) Recognition and definition of variables	(5) Significant improvement over prior alternatives
(6) Controls defined and used correctly	(6) Performance testing performed
(7) Data supports the conclusions	
(8) Data limitations identified	
(9) Reference to related research	
(10) Evidence of literature search	

2. Creative Ability (30 points)
   Points are awarded for:
   (1) Originality in selecting the problem
   (2) Originality of plan to solve the problem
   (3) Originality in the use or construction of equipment
   (4) Originality in the analysis and interpretation of data

3. Thoroughness (15 points)
   Points are awarded for:
   (1) Completeness of the project within the scope of the problem
   (2) Evidence of a literature search
   (3) Awareness of theoretical background
   (4) Completeness of observations and data

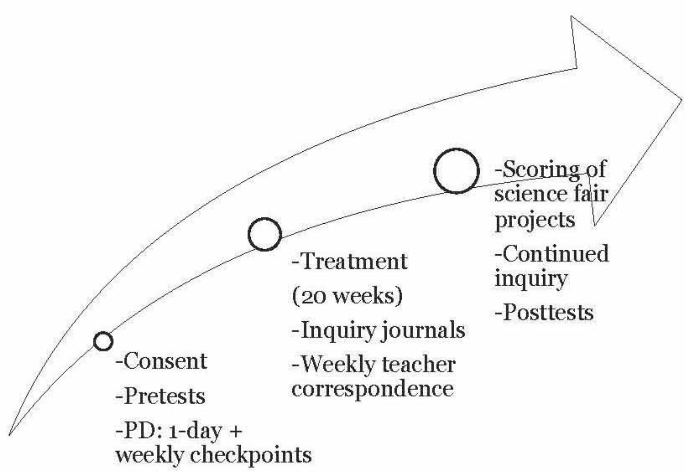
4. Skill (15 points)
   Points are awarded for:
   (1) Evidence that the student/team has the required laboratory, computation, observational and design skills to perform a meaningful investigation
   (2) Refinement of various components of the project

5. Clarity (10 points)
   Points are awarded for:
   (1) Problem and results that are understandable
   (2) Clarity of data presented (purpose, procedure and conclusions)
   (3) Clarity of project display
   (4) Orderly arrangement of display

Maximum possible score = 100 points Taken from:
http://www.ctsciencefair.org/student_guide/actualjudge.html

8

Data Collection Procedures and Timeline

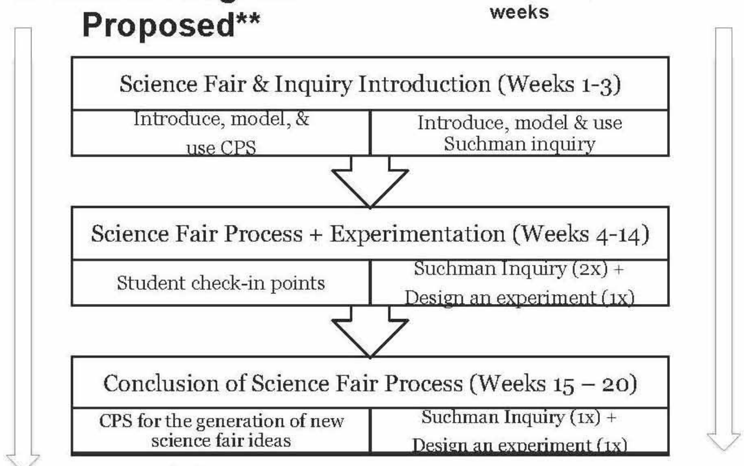


Treatment characteristics

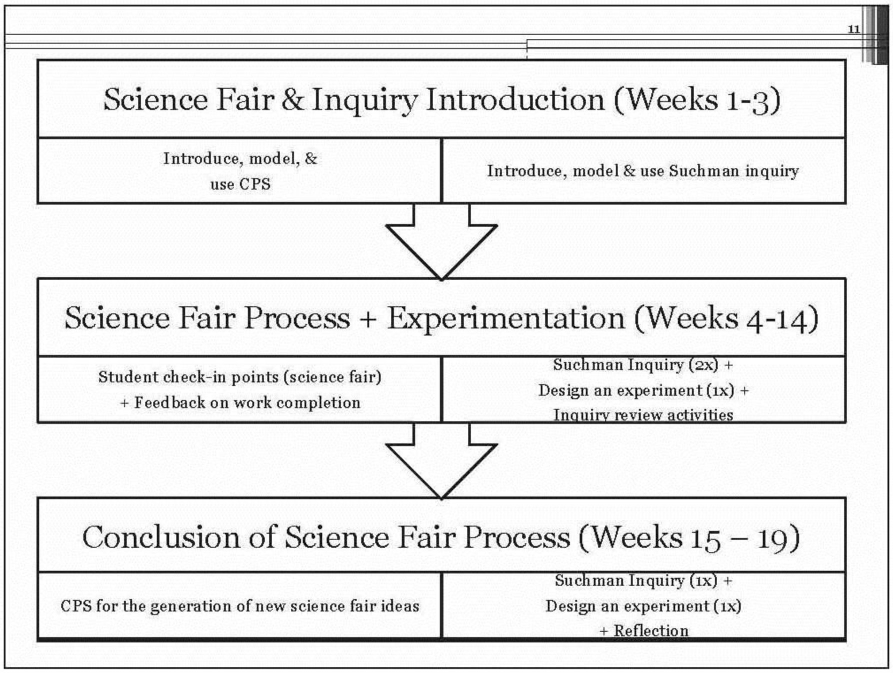
- Science Curriculum
  - Science fair process
  - Lab activities based upon state science inquiry standards
- Creative and Critical Thinking Skills
  - Creative Problem Solving (CPS) Model (Treffinger & Isaksen, 1985)
  - Suchman Inquiry Model (Suchman, 1968)

INQUIRY Program – Proposed**

Weekly check-in meetings & follow-up sessions for 20 weeks



Treatment Timeline



Expectations

- Data
- Weekly check-in meetings
- Inquiry journals – lab work
- 3 inquiry reflections
- Related inquiry activities
- State embedded tasks & curriculum
- Honesty

13

Limitations of the Study

- No random assignment to group
- Intact groups
- Prior knowledge of inquiry of the teachers

- **Common grade-level department planning time (Professional Learning Communities established)**
- **Bias in science fair ratings**

Why Inquiry?

Example of scenario using the Suchman Inquiry Model

- Step 1: Selecting a puzzling situation (**problem**) related to your curriculum that is interesting and stimulating to the learner.

- Example:
- *Two plants growing in the classroom receive the same amount of water and are planted in the same soil, yet one of the plants is much larger than the other. The plants were replanted from seedlings that were exactly the same size. What might cause this difference in plant growth?*

Suchman Inquiry Model

- Teacher explain process to class
- Teacher = main source of data; will only respond to questions with a "yes" or "no"
- The responsibility for hypothesizing is on students
- Rules:
- 1 A student may only ask a question when called upon
- 2 Students may only talk to each other during cooperative group time
- 3 Questions must be phrased so teacher answers with a yes or no
- 4 Students can continue to ask questions
- Example:
- *Student: Are the plants of the same genus?*
- *Teacher: Yes*

Suchman Inquiry Model

- Step 2 Gathering data
- As students ask questions, all questions from the class are recorded in a lab notebook or on the board, along with the teacher's response of yes or no
- Acceptable example:
- *Does the plant lean toward the sun because of magnetic force?*
- Unacceptable example:
- ~~What makes a plant lean towards the sun?~~

Suchman Inquiry Model

- Step 3 Develop hypotheses
- Once a student poses a question that is a possible answer to the problem, a hypothesis (or hypotheses) is recorded on the board in a designated spot.
- Others can be recorded as well.
- All data gathering in class relates directly to accepting or rejecting this theory
- Cooperative grouping is acceptable in this phase
- Teacher encourages students to consider all types of questions
- Possible student hypothesis:
- *"If both plants are placed in the same part of the room, then their growth be the same."*

Suchman Inquiry Model

- Step 4 Organize the data & Formulate explanation
- Organize the data (evidence) and formulate an explanation for the puzzle. Be prepared to defend this explanation.

- Example:
- *"Plants need sunlight to grow strong and healthy."*
- Students then inquire if theory can be generalized to other situations?
- Students record flaws in theory

Suchman Inquiry Model

- Step 5 Analyze the Process
- Students review the process upon acceptance of the theory
- Students analyze the questions they have asked and recorded
- Students discover how they could have asked more effective questions
- Teacher may surrender some of the control and facilitating in order to allow students to design their own inquiry processes (*OPEN-INQUIRY*)

Suchman Inquiry Model

- Step 6 Evaluate
- **Ask students to create 2-3 more puzzling situations that can be investigated.**
- A possibility if time permits:
  - Incorporate a contest for the most intriguing and interesting problems.

Suchman Inquiry Model

- Where do we go next?
- At the conclusion of this process, students will develop a habit of asking questions and discovering answers with guided support from the teacher

(a.k.a. guided-inquiry)

Suchman Inquiry 8th grade example

- 1. As you know, if you live in Bethel, you most likely have a septic system. Many synthetic cleaning products, pharmaceuticals, and other chemicals used in the house that are poured down the sink can be toxic to humans, pets, plants, and wildlife. Microorganisms in the soil treat wastewater before it reaches the ground water, preventing pollution and public health hazards. Even though this is true, suggest what might account for a decrease in the fish population.

- CT Science standard 6.4, C7

Suchman Inquiry 8th grade example

- 2. Rock strata in the eastern United States are very similar. In Florida, however, the rock strata are extremely different from any other area. What might account for this dramatic difference?

- CT standard 7.3, C12

Suchman Inquiry 7th grade example

- 1. Anemia is a condition in which the body does not have enough healthy red blood cells (RBCs). Leukemia is a condition in which a person's white blood cell (WBC) count is extremely high. Based on Mr. Muharem's blood test, you will notice that he has an elevated WBC count and a low RBC count. You are called in to assist Dr. Reynolds in diagnosing this patient. What could be the result of this finding? (Blood test will be provided.)

- CT standard 7.2, C10 & C.INQ 9

Suchman Inquiry 7th grade example

- 2. What provides a valid DNA sample criminal investigation purposes?

- State Standards:

8.2, C27 & C.INQ. 8 & C.INQ. 9

Q+a

THE TELLTALE PART

VICTORIA ROBERTS

Q. What provides a valid DNA sample for criminal identification purposes? Can investigators get DNA from, say, perspiration, saliva, urine or earwax as well as from semen or a cheek swab?

A. While not all these bodily substances provide ideal DNA samples, testable DNA can often be extracted from all of them. In every case, what is being tested is the DNA contained in cells of human tissue, whether found on their own or carried by another substance, like earwax, sweat or mucus. Shed cells are also found in urine and feces, vomit, and even tears.

Not all such samples are routinely accepted by testing laboratories, but with modern techniques even a few cells can provide a DNA profile.

A variety of materials can be collected at a crime scene and investigated for DNA. For example, dirty laundry can yield traces of blood, sweat or semen; the nosepiece and ear pieces of a pair of

Now, you try a Suchman example…

- *Three petri dishes in the classroom are placed in the same environment and receive the same food, yet one of the petri dishes produces many more bacterial colonies than the other two dishes. What might cause this difference in bacterial growth?*

- State Standard 7.4 & C.INQ. 3 & C. INQ. 4

Creative Problem Solving (CPS)

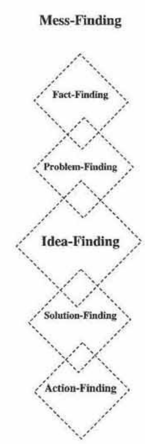
Dr. Delcourt

The Creative Problem Solving (CPS) Model 29

CPS Model (Treffinger & Isaksen, 1985)

Stages of the CPS Model

1. ***Mess-Finding*** (Looking at the "mess" of interrelated issues, challenges, problems, and opportunities to find an area on which to focus).
2. ***Fact-Finding*** (exploring knowns, unknowns, issues, challenges, missing or needed information to expand understanding of the mess).
3. ***Problem-Finding*** (Discovering a suitably "fuzzy" problem, rife with opportunity or need for unusual and novel solutions and approaches).
4. ***Idea-Finding*** (Generating a large number of diverse and novel ideas relating to the problem).
5. ***Solution-Finding*** (Converging on a subset of ideas, synthesizing and refining them into potentially useful solutions, and exploring barriers and approaches to acceptance).
6. ***Action-Finding*** (Generating and refining potential action steps to move the solutions through acceptance and into implementation).

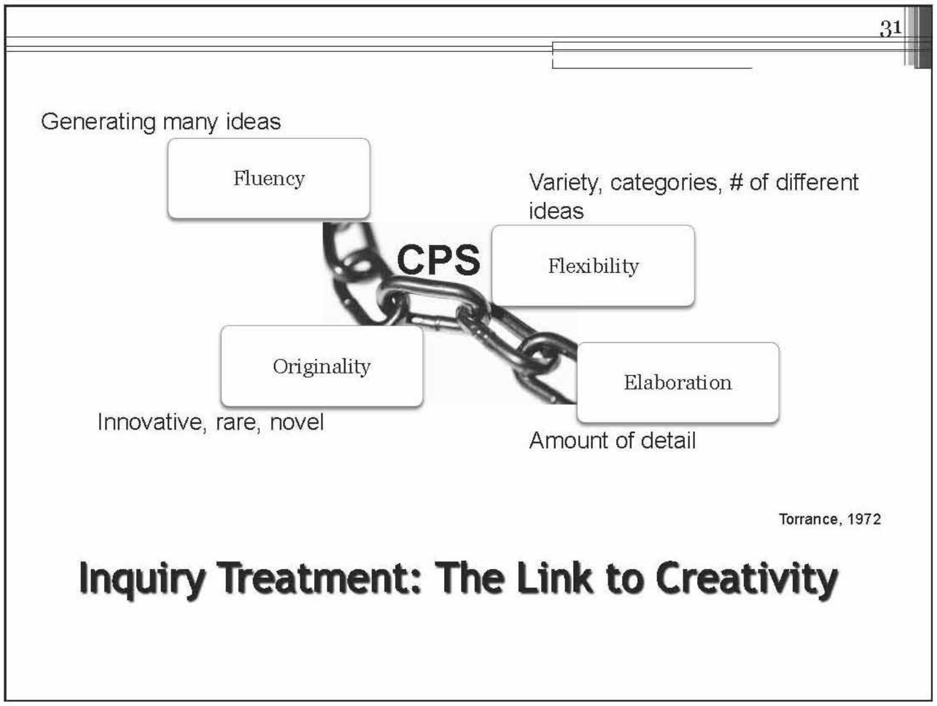


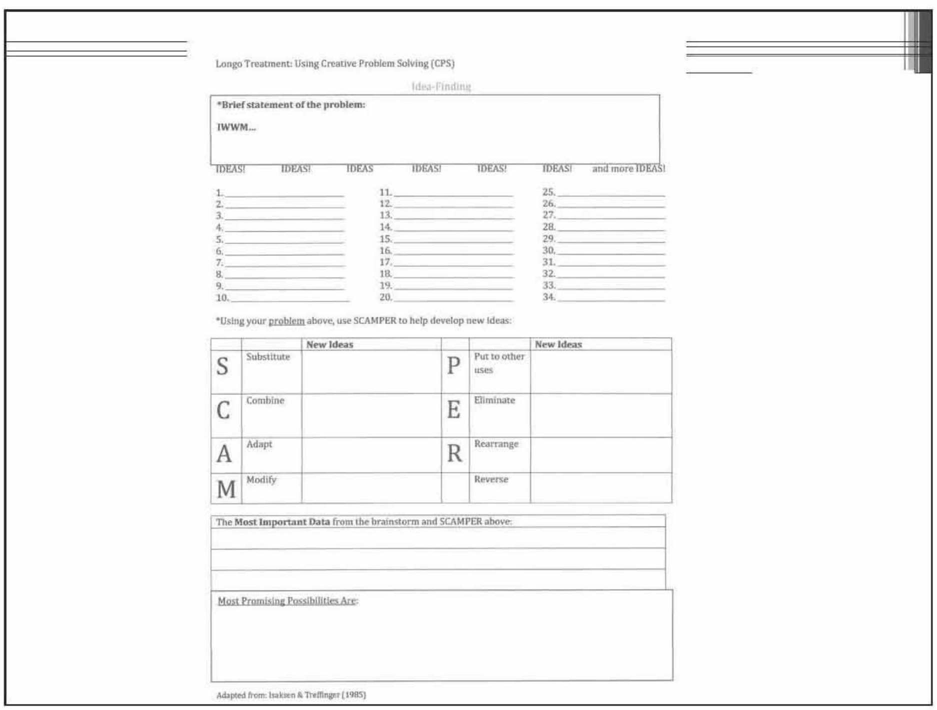
←Divergent→ thinking

Brainstorming rules

- 1 Quantity
- 2 Combining ideas is welcome
- 3 Crazy ideas ("Freewheeling")
- 4 Defer judgment (wait to judge)

Osborne, 1953





Longo Treatment: Using Creative Problem Solving (CPS)

Idea-Finding

***Brief statement of the problem:**

IWWM…

IDEAS! IDEAS! IDEAS IDEAS! IDEAS! IDEAS! and more IDEAS!

1. ____	11. ____	25. ____
2. ____	12. ____	26. ____
3. ____	13. ____	27. ____
4. ____	14. ____	28. ____
5. ____	15. ____	29. ____
6. ____	16. ____	30. ____
7. ____	17. ____	31. ____
8. ____	18. ____	32. ____
9. ____	19. ____	33. ____
10. ____	20. ____	34. ____

*Using your problem above, use SCAMPER to help develop new ideas:

		New Ideas			New Ideas
S	Substitute		P	Put to other uses	
C	Combine		E	Eliminate	
A	Adapt		R	Rearrange	
M	Modify			Reverse	

The **Most Important Data** from the brainstorm and SCAMPER above:

Most Promising Possibilities Are:

Adapted from: Isaksen & Treffinger (1985)

Thank you for participating in this research study.

Appendix B: Suchman Inquiry Model

Suchman Inquiry Investigation
*Adapted from the Suchman Inquiry Model (Suchman, 1968)

Name ____________________________________

Step 1: Identify the puzzling situation.

Step 2: Gather information about the topic by asking "Yes/No" questions related to your puzzling situation or dilemma. First, discuss with your group. Next, walk around the classroom and inquire from other students, again, using only "yes/no" questions. Document your findings.

Step 3: Develop a hypothesis based on your information. Discuss the hypothesis with your group and/or others in the class. If verified by the class, write the hypothesis on the board for whole group discussion. The class will verify each hypothesis. If the class does not accept, data gathering continues and new hypotheses are created.

Step 4: Re-write the hypothesis that the class chooses. Organize the data (evidence) and formulate an explanation for the puzzling situation. Be prepared to defend this explanation.

Hypothesis:
Evidence:

Step 5: Analyze & evaluate your inquiry process and propose improvements.

Step 6: Create 2-3 more puzzling situations that can be investigated.

1
2
3

*Adapted from the Suchman Inquiry Model (Suchman, 1968)

Appendix C: Description of Inquiry-related Activities

Lessons Using the Suchman Inquiry Model

In seventh grade, the teacher first used the Suchman model during week 4 (the week of December 20, 2010). Students were presented with a puzzling situation designed by the researcher and modeled in the professional development workshop. Students were asked to respond to this puzzling situation using the Suchman model template provided by the researcher:

> Anemia is a condition in which the body does not have enough healthy red blood cells (RBCs). Leukemia is a condition in which a person's white blood cell (WBC) count is extremely high. Based on the patient's blood test in your handout, you will notice that he has an elevated WBC count and a low RBC count. You are called in to assist the doctor in diagnosing this patient. What could be the result of this finding? (Blood test provided.)

The second Suchman activity in seventh grade classrooms was conducted during the week of February 28, 2011 (week 13). Students were asked to respond to a puzzling situation based on bacterial growth (the same activity used by the eighth grade teacher modeled in the workshop).

In eighth grade, the teacher first used the Suchman model the week of January 10, 2011 (week 6). Students were presented with a puzzling situation designed by the researcher and modeled in the professional development workshop. Students were asked to respond to this puzzling situation using the Suchman model template adapted by the researcher (Appendix B):

Three petri dishes in the classroom are placed in the same environment and receive the same food, yet one of the petri dishes produces many more bacterial colonies than the other two dishes. What might cause this difference in bacterial growth?

The second Suchman activity in eighth grade classrooms was conducted during week 11 (week of February 14, 2011). Students were asked to respond to this puzzling situation using the Suchman model template:

As you know, if you live in our town, you most likely have a septic system. Many synthetic cleaning products, pharmaceuticals, and other chemicals used in the house that are poured down the sink can be toxic to humans, pets, plants, and wildlife. Also, microorganisms in the soil treat wastewater before it reaches the ground water, preventing pollution and public health hazards. Even though this is true, suggest what might account for a decrease in the fish population.

The third and final Suchman activity conducted in eighth grade classrooms took place during the week of April 4, 2011 (week 18). Students were asked to respond to this puzzling situation using the Suchman model template:

Researchers continue to puzzle over whether global warming is a normal variation in climate or a result of human activity. Weather forecasters have been inaccurate many, many times. On February 14th, temperatures hit record highs across Connecticut, hitting a winter high of 59 degrees in our town. What is the primary reason for this phenomenon?

Seventh Grade Inquiry Lessons

The *Huff and Puff Respiration* inquiry lab was introduced to seventh-grade students by the teacher as follows:

Using only two index cards, two straws of a different interior diameter and a metric ruler, design an experiment that will demonstrate how a reduction in airflow affects the ability to perform physical activities.

After brainstorming in groups of three or four, students created two testable problem questions. One of these questions was chosen for investigation and the experiment was performed. Students were asked to document their work in the form of a lab report. Students completed the following in conjunction with their experiment: identification of all independent, dependent variables and control; hypothesis, procedural plan write up; creation of a data table and graph; and conclusion.

The *Feel the Beat* inquiry lab, an embedded task from the state, asked students to design a procedure to explore how different types of activity affect pulse rate. Students were to describe how they would change the independent variable, measure the dependent variable, keep the other factors constant in the experiment, and consider multiple trials to gain confidence in the results. Similar to the last inquiry lab, students wrote a lab report that included the following: Problem question; identification of all independent, dependent and control variables; hypothesis; procedure; creation of a data table and graph; conclusion; and follow up research on the human cardiovascular system. Upon completion, students moved to the second part of this investigation, which followed the same template but examined the effects of other independent variables other than physical activity.

Eighth Grade Inquiry Lessons

The *Dig In* inquiry lab, an embedded task from the state, asked eighth grade students to design a procedure to explore a soil property that may affect the ability to hold water. Students were to describe how they would change the independent variable, measure the dependent variable, keep the other factors constant in the experiment, and conduct multiple trials. Students wrote a lab report that included the following: Problem question; identification of all independent, dependent variables and control; hypothesis; procedure; creation of a data table and graph; conclusion; and follow up research on various soil types. Upon completion, students moved to the second part of this investigation, which followed the same template but examined the effects these soil types on water percolation.

The *Fluff and Puff* inquiry lab was introduced to students by the teacher by the following prompt:

> If you ever watched clouds, sometimes it seems that they form out of nowhere. Clouds form because as the air cools, the water vapor contained in it begins to condense. But is temperature the only factor that controls how fast a cloud forms? Design an experiment using the items at your lab table in which you will demonstrate your cloud making abilities.

After brainstorming in groups of three or four, students created two testable problem questions. One of these questions was chosen for investigation and the experiment was performed. Students were asked to document their work in the form of a lab report. Students completed the following in conjunction with their experiment: identification of all independent, dependent variables and control; hypothesis, procedural plan write up; creation of a data table and graph; and conclusion.

The *Friction Foes* inquiry lab began with students being introduced to the following prompt:

> If you have ever seen a video of an avalanche or landslide, you have observed the destruction that these events can trigger. As you know, gravity is a constant force

> working in our universe. When natural disasters such as avalanches and landslides occur, the friction between the snow or rocks and the underlying ground has been overcome. Items such as water, ice, and sand can overcome friction and cause these disastrous events. These items act as lubricants and reduce or eliminate friction. Use the items at your lab table to represent items found in nature and demonstrate your understanding of the relationship between friction and mass movement.

After brainstorming in groups of three or four, students created two testable problem questions. One of these questions was chosen for investigation and the experiment was performed. Students were asked to document their work in the form of a lab report. Students completed the following in conjunction with their experiment: identification of all independent, dependent variables and control; hypothesis, procedural plan write up; creation of a data table and graph; and conclusion.

Appendix D: Creative Problem-solving Worksheets

CPS Process, BMS Science fair

**Adapted from Treffinger & Isaksen, 1985*

1. Mess-Finding

List some messes (science fair project ideas):

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

*Circle your top 3 ideas above so far.

2. Data-Finding

Using your top 3 ideas (messes) above, complete the "5W's and an H" for each.

	NEED/LIKE TO KNOW Idea #1	NEED/LIKE TO KNOW Idea #2	NEED/LIKE TO KNOW Idea #3
WHO			
WHAT			
WHERE			
WHEN			
WHY			
HOW			

3. Problem-Finding

Create problem questions using this format:
IWWM… = In What Ways Might…

	DO WHAT?
IWWM…	
IWWM…	
IWWM…	
IWWM…	

4. Idea-Finding

***Brief statement of one problem above:** **IWWM…**

*Using your problem above, use SCAMPER to help develop new ideas:

		New Ideas			**New Ideas**
S	Substitute		**P**	Put to other uses	
C	Combine		**E**	Eliminate	
A	Adapt		**R**	Rearrange	
M	Modify			Reverse	

5. Solution-Finding

Rank each criteria below for your possible solutions.

3= Easy or Positive
2 = OK
1 = Difficult

	Criteria							
SOLUTIONS	Cost	Time	Availability of materials	Motivation	Interference with School	Other	Other	**Total**
1.								
2.								
3.								
4.								
5.								

6. Acceptance-Finding

Create a plan of action.

Appendix E: Science Inquiry Reflection

Science Inquiry Reflection

Step 1) List each of the following ITEMS into 1 of the 2 columns <u>in step 2</u>:

- States **PROBLEM** or **QUESTION**
- Includes a **HYPOTHESIS**
- Lists <u>more than</u> **3 STEPS**
- Arranges steps in **SEQUENTIAL** order
- Lists **MATERIALS** needed
- Plans to practice **SAFETY**
- Uses **MULTIPLE TRIALS**
- Includes **CONSTANT VARIABLES**:
- Includes any type of **MEASUREMENT**
- Includes a **1 GRAPH** or **1 TABLE**
- Creates a **CONCLUSION**

Step 2) Reflect on your inquiry skills. Complete the T-chart by using the items in the list in Step 2 below.

Item that I included in my science fair experiment.	**Items that I <u>did not</u> include in my science fair project.**

3) Respond to the following question by writing **1 paragraph (**5-7 sentences) in your notebooks**:**

Using your T-chart above, write about what <u>improvements</u> you can make to the way you design and carry out experiments.

Appendix F: Science Process Skills Assessment, Form A: The Diet Cola Test

SCIENCE SKILLS : DESIGNING AN EXPERIMENT -FORM A

DIRECTIONS:

How would you do **a fair test** of this question:

"Are bees attracted to Diet Cola?" (In other words, do bees **like** Diet Cola?) Tell how you would test this question. Be as scientific as you can as you write about your test. Write down the steps you would take to find out if bees like diet cola.

(Fowler, 1990)

Appendix G: Connecticut Science Fair Project Rubric

Connecticut Science Fair Project Rubric

1. Scientific Thought/Engineering Goals (30 points)
   Points are awarded for:

   Scientific
   (1) Evidence of use of scientific method
   (2) Clear statement of a problem
   (3) Problem is limited and soluble
   (4) Evidence of a procedural plan
   (5) Recognition and definition of variables
   (6) Controls defined and used correctly
   (7) Data supports the conclusions
   (8) Data limitations identified
   (9) Reference to related research
   (10) Evidence of literature search

   Engineering
   (1) Identification of clear objectives
   (2) Objective relevant to user needs
   (3) Solution is - workable, acceptable to user, economically feasible
   (4) Solution compatible with potential end product
   (5) Significant improvement over prior alternatives
   (6) Performance testing performed

2. Creative Ability (30 points)
   Points are awarded for:
   (1) Originality in selecting the problem
   (2) Originality of plan to solve the problem
   (3) Originality in the use or construction of equipment
   (4) Originality in the analysis and interpretation of data

3. Thoroughness (15 points)
   Points are awarded for:
   (1) Completeness of the project within the scope of the problem
   (2) Evidence of a literature search
   (3) Awareness of theoretical background
   (4) Completeness of observations and data

4. Skill (15 points)
   Points are awarded for:
   (1) Evidence that the student/team has the required laboratory, computation, observational and design skills to perform a meaningful investigation
   (2) Refinement of various components of the project

5. Clarity (10 points)
   Points are awarded for:
   (1) Problem and results that are understandable
   (2) Clarity of data presented (purpose, procedure and conclusions)
   (3) Clarity of project display
   (4) Orderly arrangement of display

Maximum possible score = 100 points Taken from:
http://www.ctsciencefair.org/student_guide/actualjudge.html

Appendix H: Torrance Subscale Follow-up Data

TTCT Figural, Form B Posttest Subscale Data

TTCT Subscale	Program Type	*M*	*SD*	*n*
Fluency	Direct Instruction	99.06	9.756	116
	Inquiry instruction	103.16*	12.454	108
	Total	101.04	11.301	224
Originality	Direct Instruction	96.09	10.888	116
	Inquiry instruction	95.71	12.064	108
	Total	95.91	11.446	224
Elaboration	Direct Instruction	91.33**	12.812	116
	Inquiry instruction	87.11	11.482	108
	Total	89.29	12.344	224
Abstractness of	Direct Instruction	90.49	15.690	116
Titles	Inquiry instruction	87.92	14.972	108
	Total	89.25	15.368	224
Resistance to	Direct Instruction	66.47***	11.870	116
Premature Closure	Inquiry instruction	59.82	10.341	108
	Total	63.26	11.620	224

Note. As a follow up to the data analyses, the Torrance Test of Creative Thinking (TTCT) overall creativity index score was substituted with the five TTCT subscale scores. The fluency subscale scores produced significant results in favor of the inquiry instruction group. The elaboration and closure subscale scores produced significant results in favor of the direct instruction group. *$p < .05$, **$p < .01$, ***$p < .001$

Appendix I: Letter and Consent Form (Superintendent)

WESTERN CONNECTICUT STATE UNIVERSITY

Department of Education and Educational Psychology
181 White Street
Danbury, CT 06810

November 2010
Dear (Superintendent):

I am currently enrolled in the doctoral program for Instructional Leadership at Western Connecticut State University. This program requires that I design and implement a dissertation research study. The purpose of this 20-week study is to determine the effects of an inquiry-based learning program on critical thinking, science process skills, creativity, and science fair achievement of middle school students in grades 7 and 8.

The *California Measure of Mental Motivation* (CM3) assesses critical thinking; *The Diet Cola Test* surveys science process skills, *The Torrance Test of Creative Thinking (TTCT)* measures creativity, and the *Connecticut Science Fair Project Rubric* is used to rate science fair achievement. Students in both treatment and comparison groups will complete the first 3 of these assessments and trained raters, who do not teach the students, will gather information about science fair projects. All surveys will be administered via paper and pencil. Each assessment tool to be completed by the students will take approximately 15-20 minutes to administer.

This research study has been reviewed and approved by Western Connecticut State University's Institutional Review Board. Participation in this study is completely voluntary and subjects may withdraw at any time. Students who agree to participate will submit all information to the researcher. The classroom teacher will not know which students and parents have given their consent to participate in the study. Therefore, program participation will not impact a student's science grade. Privacy will be protected. Subjects' (district, school, teacher, student) will be numerically coded. All identities will be maintained in a secure location to protect confidentiality. Results will only be reported in aggregate form.

Teachers who agree to participate in the inquiry curriculum model will receive a 1-day workshop and weekly coaching. Upon completion of the project, teachers who were not trained using this curriculum will have the opportunity to engage in professional development related to this instructional model. A description of the final project will be available to all school personnel.

I wish to thank administrators in the Bethel Public School district for considering participation in this study. It is hoped that results of this investigation will enable educators to better understand outcomes related to inquiry learning. If you have any questions, please feel free to contact me.

Sincerely,

Christopher M. Longo
longoc@sbcglobal.net

Marcia Delcourt, PhD
Coordinator, EdD in Instructional Leadership
delcourtm@wcsu.edu

I agree that the study described above can be conducted in (name of school district).

Please Print Name	Signature	Date

Appendix J: Letter and Consent Form (Associate Superintendent)

WESTERN CONNECTICUT STATE UNIVERSITY

Department of Education and Educational Psychology
181 White Street
Danbury, CT 06810

November 2010
Dear (Associate Superintendent):

I am currently enrolled in the doctoral program for Instructional Leadership at Western Connecticut State University. This program requires that I design and implement a dissertation research study. The purpose of this 20-week study is to determine the effects of an inquiry-based learning program on critical thinking, science process skills, creativity and science fair achievement of middle school students in grades 7 and 8.

A total of four quantitative instruments will be used in this study. The *California Measure of Mental Motivation* (CM3) assesses critical thinking; *The Diet Cola Test* surveys science process skills, *The Torrance Test of Creative Thinking (TTCT)* measures creativity, and the *Connecticut Science Fair Project Rubric* is used to rate science fair achievement. Students in both treatment and comparison groups will complete the first 3 of these assessments and trained raters, who do not teach the students, will gather information about science fair projects. All surveys will be administered via paper and pencil. Each assessment tool to be completed by the students will take approximately 15-20 minutes to administer.

This research study has been reviewed and approved by Western Connecticut State University's Institutional Review Board. Participation in this study is completely voluntary and subjects may withdraw at any time. Students who agree to participate will submit all information to the researcher. The classroom teacher will not know which students and parents have given their consent to participate in the study. Therefore, program participation will not impact a student's science grade. Privacy will be protected. Subjects' (district, school, teacher, student) will be numerically coded. All identities will be maintained in a secure location to protect confidentiality. Results will only be reported in aggregate form.

Teachers who agree to participate in the inquiry curriculum model will receive a 1-day workshop and weekly coaching. Upon completion of the project, teachers who were not trained using this curriculum will have the opportunity to engage in professional development related to this instructional model. A description of the final project will be available to all school personnel.

I wish to thank administrators in the Bethel Public School district for considering participation in this study. It is hoped that results of this investigation will enable educators to better understand outcomes related to inquiry learning. If you have any questions, please feel free to contact me.

Sincerely,

Christopher M. Longo
longoc@sbcglobal.net

Marcia Delcourt, PhD
Coordinator, EdD in Instructional Leadership
delcourtm@wcsu.edu

I agree that the study described above can be conducted in (name of school district).

Please Print Name	Signature	Date

Appendix K: Cover Letter and Consent Form (Principal)

WESTERN CONNECTICUT STATE UNIVERSITY

Department of Education and Educational Psychology
181 White Street
Danbury, CT 06810

Dear (Principal):

I am currently enrolled in the doctoral program for Instructional Leadership at Western Connecticut State University. This program requires that I design and implement a dissertation research study. The purpose of this 20-week study is to determine the effects of an inquiry-based learning program on critical thinking, science process skills, creativity and science fair achievement of middle school students in grades 7 and 8.

A total of four quantitative instruments will be used in this study. The *California Measure of Mental Motivation* (CM3) assesses critical thinking; *The Diet Cola Test* surveys science process skills, *The Torrance Test of Creative Thinking (TTCT)* measures creativity, and the *Connecticut Science Fair Project Rubric* is used to rate science fair achievement. Students in both treatment and comparison groups will complete the first 3 of these assessments and trained raters, who do not teach the students, will gather information about science fair projects. All surveys will be administered via paper and pencil. Each assessment tool to be completed by the students will take approximately 15-20 minutes to administer.

This research study has been reviewed and approved by Western Connecticut State University's Institutional Review Board. Participation in this study is completely voluntary and subjects may withdraw at any time. Students who agree to participate will submit all information to the researcher. The classroom teacher will not know which students and parents have given their consent to participate in the study. Therefore, program participation will not impact a student's science grade. Privacy will be protected. Subjects' (district, school, teacher, student) will be numerically coded. All identities will be maintained in a secure location to protect confidentiality. Results will only be reported in aggregate form.

Teachers who agree to participate in the inquiry curriculum model will receive a 1-day workshop and weekly coaching. Upon completion of the project, teachers who were not trained using this curriculum will have the opportunity to engage in professional development related to this instructional model. A description of the final project will be available to all school personnel.

I wish to thank administrators in the Bethel Public School district for considering participation in this study. It is hoped that results of this investigation will enable educators to better understand outcomes related to inquiry learning. If you have any questions, please feel free to contact me.

Sincerely,

Christopher M. Longo	Marcia Delcourt, PhD
	Coordinator, EdD in Instructional Leadership
longoc@sbcglobal.net	delcourtm@wcsu.edu

I agree that the study described above can be conducted in (name of school).

________________________ __________________________ ________

Please Print Name Signature Date

Appendix L: Parental Consent form for Minors to Participate in a Research Study

WESTERN CONNECTICUT STATE UNIVERSITY

Department of Education and Educational Psychology
181 White Street
Danbury, CT 06810

November 2010
Dear Parent/Guardian,

I am currently enrolled in the doctoral program for Instructional Leadership at Western Connecticut State University. This program requires that I design and implement a dissertation research study. The purpose of this 20-week study is to determine the effects of an inquiry-based learning program on middle school students in grades 7 and 8.

Information will be collected about students' critical thinking skills, science process skills, and creativity. Each assessment will take approximately 15-20 minutes to complete. Data will be collected at the beginning and end of the project. In addition, students will keep a science fair journal that documents their ideas as they develop their science fair projects. All students will participate in the regular science curriculum. Some students will be taught using specific inquiry strategies.

While your child's progress in science class and his or her science fair project will be assessed by the classroom teacher, as is usual, science fair projects will also be assessed by independent raters, not affiliated with your child's school program.

This research study has been reviewed and approved by Western Connecticut State University's Institutional Review Board. Participation in this study is completely voluntary. Individuals may withdraw from the project at any time. Students who agree to participate will submit all information to the researcher. The classroom teacher will not know which students and parents have given their consent to participate in the study. Therefore, program participation will not impact a student's science grade. Privacy will be protected. Student names will be numerically coded. All student identities will be maintained in a secure location to protect confidentiality. Results will only be reported in aggregate form.

I wish to thank administrators in the Bethel Public School district for participating in this study. It is hoped that results of this investigation will enable educators to better understand outcomes related to inquiry learning. If you have any questions, please feel free to contact me.

Sincerely,

Christopher M. Longo
longoc@sbcglobal.net

Marcia Delcourt, PhD
Coordinator, EdD in Instructional Leadership
delcourtm@wcsu.edu

I agree that my child ______________________can participate in the Science Inquiry Study.
I am at least 18 years of age or older.

___________________________ ______________________________ _________
Please Print Name Signature Date

Appendix M: Cover Letter and Assent Form (Student)

Department of Education and Educational Psychology
181 White Street
Danbury, CT 06810

Student Information Form to Participate in a Research Study

November 2010

Dear Student,

I am in a doctoral program at Western Connecticut State University. I am doing an exciting research study about strategies for teaching science. I would like you to be a part of my study. I will send a permission slip home with you. But first, I would like you to know more about my project.

The study is about the ways in which you think about science. I will ask you to complete a few surveys. These will include a questionnaire about thinking skills, 3 short creative activities, and a survey about science procedures. I will ask you complete this information two times during the year. Your science fair projects will also be rated by science teachers who are not from your school. These raters are very interested in the types of projects created by middle school students. Lastly, I would like to review your science journals to understand how you developed your science fair ideas.

I will not use your name in the study; I will use numbers. The surveys will have nothing to do with report card grades and the additional science fair ratings will not be reported to your science teacher. All of the information will be kept private. Your participation is voluntary and you can withdraw from the study at any time. If you have any questions, please ask me.

If you would like to be in my study, please print and sign your name below:

____

Print student name

X____

Student signature

Thank you,

Mr. Christopher M. Longo

longoc@sbcglobal.net

Marcia Delcourt, PhD
Coordinator, EdD in Instructional Leadership
delcourtm@wcsu.edu