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The impact of Project Lead The Way gateway to technology foundation unit completion on students' critical-thinking skills

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The Impact of Project Lead The Way Gateway to Technology Foundation Unit Completion on Students' Critical-Thinking Skills

By

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Dedication

To Almighty Allah (God), who facilitated for me all means and provided me with skills, abilities, and time to complete this dissertation

To Prophet Mohamed, peace and blessings of Allah be upon him, whose guidance and teachings always encouraged me to continue seeking knowledge and to do my best in learning and persevering on that

To my parents, Odai Hashem and Jenan Al Adham, who were always making prayers for me and who taught me many things that helped me succeed in my life

To my husband, Suleiman Ashur, who was committed to encourage and support me in my education

To my children, Asad, Fadwa, and Noor, whose love and support encouraged me to keep going in my education

And

To all the people I love for the sake of Allah who inspired me, who contributed to my education, skills, and growth, and/or who pray for me

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Abstract

Georgetown’s Public Policy Institute (2013) reported that the fastest growing occupations and the highest demand for college education and training fields will be in Science, Technology, Engineering, Mathematics (STEM), healthcare, and community services. One of the K-12 Science, Technology, Engineering, and Mathematics (STEM) programs’ purposes is to promote critical-thinking skills (Johnson, 1992). This study examined the impact of Project Lead The Way Gateway to Technology (PLTW-GTT) units, a middle school STEM program, on the critical-thinking skills of middle school students.

Quasi experimental research methods were utilized to test the impact of the completion of two PLTW-GTT foundation units on students’ critical thinking scores as measured by the California Critical Thinking Skills Test (CCTST). Participants from the sixth- and seventh-grades of a suburban middle school in a Midwestern state formed two sets of treatment and control groups. Students enrolled in the PLTW Design and Modeling (D&M) (63 participants) and Automation and Robotics (A&R) (27 students) units along with two control groups (28 and 19 respectively) completed the CCTST at the beginning and at the end of the units.

The results of the study indicated that completion of the PLTW Design and Modeling (DM) unit had a significant positive influence on participants’ critical-thinking skills when compared to the control group. The Automation and Robotics (AR) unit had no significant impact on participants’ critical-thinking skills when compared to a corresponding control group. There appeared to be some inconsistencies in the data collection steps which may have affected the AR unit results. Therefore, future studies to test the impact of the AR unit on critical thinking are recommended. An additional finding was that both of the PLTW-GTT foundation units influenced the critical-thinking skills of male and female participants similarly.

Selected results may be generalized to schools that possess similar characteristics to those possessed by the sample school. Since the sample used for this study did not include a variety of ethnicities or races, it is recommended that future studies include schools with a larger proportion of ethnic and racial diversity. Finally, there was some evidence that experiences at the sample school may be influencing students to pursue STEM careers. This phenomenon should be investigated in future studies.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

The synergy between rapidly changing technology and society creates the need for more educational tools especially those focused on improving critical-thinking skills. Such skills will enable humans to better cope with these changes (Geertsen, 2003). There is no doubt that critical thinking is a desired skill in all fields of education and the workplace (Facione, 2011). A report by Facione and Gittens included the following: "In the absence of critical thinking, one might simply follow the demands of authority, act without a full awareness of the situation, thoughtlessly do what has been done before, or do nothing when action is needed" (Insight Assessment, 2015, p.14). Carnevale, Simith, and Strohl (2013) reported that the top five skills most needed in careers are "active listening, speaking, reading comprehension, critical thinking, and writing" (p. 26). Additionally, the same report confirmed that "…skills that involve information processing and require sophisticated cost-benefit analyses such as critical thinking, complex problem-solving and decision-making…" (p. 27) are also highly valued.

The Occupational Information Network (O*NET), a job data program that is sponsored by the U.S. Department of Labor, confirmed that in many careers critical thinking is a skill that is often announced by employers as a condition for the success of their employees. Furthermore, 96 percent of all occupations rank critical thinking as either very essential or extremely essential to that occupation (cited in Carnevale, Simith, and Strohl, 2013, p. 28).

A MetLife (2011) report revealed that based on surveys administered to four groups – teachers, parents, students, and 1000 experts – at least 92 percent of them agreed that critical thinking is very important for college and career readiness and success. Thomas Friedman, the *New York Times* World journalist, in "Leadership in Action Conference" August, 1, 2013, indicated that in a world where technological changes are happening continuously, "creativity, communication, and collaboration" are becoming the most important characteristics that are needed for the workplace. He also added that in order for the U.S. to compete in the global economy, it is not enough for our children to just memorize information; they also need to become more critical thinkers since so much information is readily available by using the internet's search engines (Aspen Institute, 2013). Geertsen (2003) explained that the need for critical-thinking skills comes from the continuous and tremendous changes in information flow and transfer. This change resulted in the need for everyone in society to acquire more skills in assessing and evaluating knowledge than ever before.

Critical thinking has been described as "… the corner-stone of education" (Splitter, 1990, p. 89). Two frequently cited definitions of critical thinking are: "...whatever skills are required to recognize, analyze and evaluate arguments" (Schlecht, 1989, p. 133), and "…the art of analyzing and evaluating thinking with a view to improving it" (Paul & Elder, 2007, p. 4).

Educational, community, and career sectors have realized the need to incorporate critical-thinking skills in teaching in postsecondary institutions. Many programs and departments within higher education institutions have incorporated critical-thinking skills into some of their courses and degrees. Studies on critical thinking related courses have revealed the positive impact they have on students' learning (Ousley, 2012; David, & Brown, 2011; Garvey, & Buckley, 2011; Mastrian, K., & McGonigle, 1999; & Mingus, & Grassl, 1997).

Fyffe (1987) indicated that based on the cognitive development skills theory, children between ages 11-15, which is during middle school, develop many of their thinking skills dramatically, and by the end of this period of human life, most thinking and problem-solving skills are acquired. Therefore, it is important for the education community to pay extra attention to this period of children's lives and to give them all they need to reach their potential.

In K-12 education, critical thinking has become increasingly important especially after the adoption of the Common Core Curriculum by K-12 schools since one of the outcomes of this new curriculum is to equip students with critical-thinking skills across subject areas (Troutner, 2012). The integration of critical thinking into the K-12 schools enhances students' potential for academic achievement (Lipman, 1988). Therefore, critical thinking should be an integral part of all subjects in K-12 education (Facione, 1990).

Many K-12 schools are attempting to incorporate critical thinking into core subjects taught during elementary, middle, and high school grades (Beyer & Backes, 1990). These efforts included incorporating STEM-related curricula during Grades 6 – 12. Some examples of such specialized curricula are: "Project Lead The Way (PLTW)", "Engineering Projects in Community Service" (EPICS), and the "National Center for Engineering and Technology Education" (NCETE) (Kelley, Brenner, & Pieper, 2010). Other technology programs offered similar experiences to 6-12 students after school (Tyler-Wood, Ellison, Lim, & Periathiruvadi, 2012; Alcaraz, Kreuter, Davis, Rogers, Samways, and Bryan, 2008; Wyss, Heulskamp, & Siebert, 2012).

The focus of this study is on one of the widely implemented Project Lead The Way (PLTW) 6^{th} -12^{th} programs in the U.S. PLTW is an innovative, technology-based curriculum that focuses on teaching STEM subjects in an engineering or biomedical context. It offers alternative teaching methods to the traditional ones by implementing hands-on experiences and inquiry-based approaches that make the classes more engaging for students ("Who We Are", 2013). The middle school program, Gateway To Technology (GTT), consists of eight units: two foundation units (Automation & Robotics and Design & Modeling) and six other units (see Figure 1 below).

As of November 6, 2013, the Gateway program had been implemented in 2,275 schools in the United States; 50 of these schools were in Michigan (“About PLTW”, 2014).

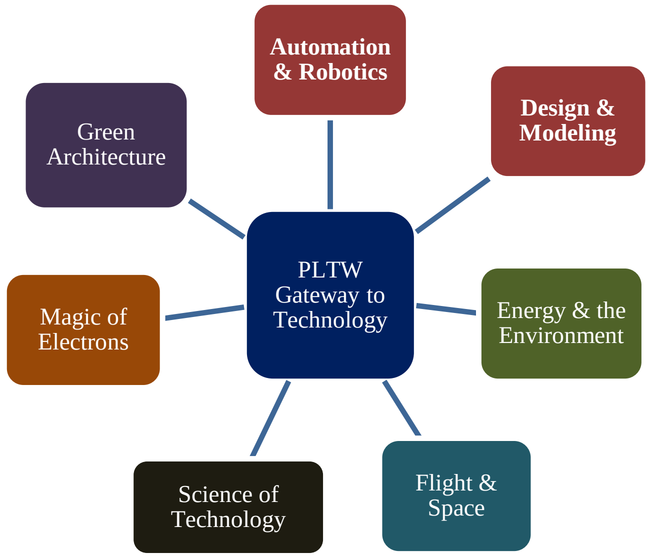

Figure 1: Project Lead The Way Gateway To Technology Program Units

This study will attempt to determine if a difference exists between the critical-thinking skills of middle school students who have completed a specific STEM-education curriculum and those who have not completed such a curriculum.

Statement of the Problem

There was some evidence that the PLTW Gateway to Technology program addresses critical thinking, but it is not fully understood whether these skills are enhanced or impacted by this program. At the same time, there is a lack of research regarding the PLTW Gateway program that addresses this topic.

Nature and Significance of the Problem

The increase of pre-engineering curriculum development and implementation in middle and high schools provides a strong rationale for evaluating what students gain through these engineering programs (Kelly, 2008). Kelley, Brenner, and Pieper (2010) explained that it is good to hear that such curricula have been developed and that many schools around the country have adopted them. But what is more important is to predict how students exposed to these classes will do in their future careers and what gains these students will make as a result of this exposure. For these reasons, educators and policy makers recognize the need for extensive research to evaluate and improve the K-12 STEM curriculum. More specifically, knowing how these programs impact students' critical-thinking skills is essential in order to justify continuing such expensive programs in schools or school districts. According to Martin and Ritz (2012, p. 39), the second most needed research area in technology education is to uncover the "benefit of K-12 Technology and Engineering Education," emphasizing the need for research in programs like PLTW.

One purpose of pre-engineering curricula taught in Grades 6 - 12 is to create problem solvers and good decision makers by teaching students critical- and cognitive- thinking skills (Johnson, 1992). Roberts (1994) emphasized that the main purpose of designing the teaching curriculum is not to change the world, but to help students learn to think. Therefore, researching STEM's impact on students' critical-thinking skills will provide a basis for evaluating the effectiveness of a key aspect of the pre-engineering curriculum (Kelly, 2008). More specifically, investigating critical-thinking skills in the Project Lead the Way GTT foundation units will help validate its purposes and goals.

Since critical thinking is perceived to be the "corner-stone of education" (Splitter, 1990, p. 89), it is important to understand what it means. There are many definitions of critical thinking (Kinney 1980; Schlecht, 1989; Splitter, 1990; Ennis, 1987; Lipman, 1988; Paul, 1993; Sternberg, 1985; O'Neill, 1997; Facione, 2011). One of the historic definitions of critical thinking is proposed by John Dewey (Dewey & Skillbeck, 1970, p. 6) "active, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it, and the further conclusions to which it tends." Another definition is "...the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action" (Paul, 1993, p. 10).

One seminal study addressing critical thinking was conducted by Facione (1990). Facione used Delphi research methods to define and categorize critical-thinking skills with the support of the American Philosophical Association (APA). The APA definition that was one of the outcomes of this research is "Critical thinking is the process of purposeful, self-regulatory judgment. This process gives reasoned consideration to evidence, context, conceptualizations, methods, and criteria." (p. 2), and "Critical thinking is using this process of purposeful, reflective judgment to decide what to believe or what to do." (Insight Assessment, 2015, p. 14).

There were six main critical-thinking skills and sub-skills identified through this seminal work. These skills and sub-skills are summarized in Table 1 below. As a result of Dr. Facione's seminal research, several forms of a critical-thinking skills test were created. These forms are called "The California Critical Thinking Skills Test" series for all different age groups covering elementary students to adults.

However, the critical-thinking theories that were the basis for this test were not tested in a STEM context such as PLTW-GTT. Therefore, more research efforts are needed to better identify the critical-thinking skills promoted in a STEM context. A quantitative study could support, modify, or add to the previous research effort. The results of this proposed study will help researchers and educators better understand whether the fundamental PLTW units address critical-thinking skills.

Table 1

List of Critical-thinking skills according to Facione's Report (1990)

Category	Subscale Category
1. Interpretation or Categorization	• Decoding Significance • Clarifying Meaning
2. Analysis or Examining Ideas	• Identifying Arguments • Analyzing Arguments
3. Evaluation or Assessing Claims	• Assessing Arguments
4. Inference or Querying Evidence	• Conjecturing Alternatives • Drawing Conclusions
5. Explanation or Stating Results	• Justifying Procedures • Presenting Arguments
6. Self-Regulation or Self-Examination	• Self-Correction

Purpose of the Study

The purpose of this study was to determine whether students' completion of either of the two PLTW GTT foundation units impact students' critical-thinking skills as measured by the CCTST when compared to students who do not complete the GTT Foundation unit.

Research Questions

This study addressed the following research questions:

1. What is the impact of the successful completion of a PLTW nine-week unit of "Design and Modeling" on middle school students' critical-thinking skills as measured by CCTST?
2. What is the impact of the successful completion of a PLTW-GTT nine-week unit of "Automation and Robotics" on middle school students' critical-thinking skills as measured by CCTST?

3. Does PLTW-GTT- Design and Modeling impact CCTST scores of female students differently than male students?
4. Does PLTW-GTT- Automation and Robotics impact the CCTST scores of female students differently than male students?
5. Is there a relationship between any of the demographic variables (i.e., *sex*, *socioeconomic status, students' future career interest, parents' education and jobs, parent's help to student in homework,* the *Usual Science Grade,* the *Usual Math Grade, MEAP [science, math, & reading]*) and the overall CCTST scores on the posttest?

Hypotheses

Null hypothesis 1: There is no significant difference between the CCTST scores of participants who have completed a GTT unit in "Design & Modeling" when compared to the scores of participants who have not completed such a GTT unit.

Null hypothesis 2: There is no significant difference between the CCTST scores of participants who have completed a GTT unit in "Automation and Robotics" when compared to the scores of participants who have not completed such a GTT unit.

Null hypothesis 3: There is no significant difference between the CCTST scores of female participants who have completed a GTT unit in "Design & Modeling" when compared to male participants who completed the same unit in the same classes.

Null hypothesis 4: There is no significant difference between the CCTST scores of female participants who have completed a GTT unit in "Automation and Robotics" when compared to male participants who completed the same unit in the same classes.

Null hypothesis 5: There is no significant correlation between any individual demographic variable (i.e., *sex, socioeconomic status, students' future career interest, parents' education and* *jobs, parents' help to student in homework,* the *Usual Science Grade,* the *Usual Math Grade, MEAP [science, math, & reading]*) and the overall CCTST posttest scores.

Limitations and Delimitations

<u>The limitations included:</u>

1. The number of participants in the study from each group, control or experimental, depended on the number of students who agreed to participate and their parents, and what can be accessed by the middle school teachers and leaders.
2. Demographics, gender, and learning needs of students may vary between the control group and the experimental group.

<u>The delimitations included:</u>

- The sample will be delimited to two groups of sixth- and seventh- grade students from a suburban Michigan middle school/s.
- The experimental group contains students who are enrolled in PLTW-GTT foundation units and the equivalent control group contains students who are not currently enrolled in a PLTW-GTT basic unit.

Assumptions

The following list of assumptions will be used as a foundation for this study:

1) Students from both the experimental and control groups have similar demographic and background characteristics to each other.
2) Participants in this research are able to understand the test questions.
3) Participants in this research will give their opinions honestly and clearly while answering the demographic questions.
4) Participants in this research will do their best while answering the test questions.

5) School administrators and parents are willing to allow participation in this research study.

Definition of Terms

The following definitions are given to provide a foundation for communication:

Project Lead The Way (PLTW) is one of the leading provider of rigorous and innovative Science, Technology, Engineering, and Mathematics (STEM) education curricular programs used in middle and high schools across the U.S. ("Who We Are", 2013).

The PLTW Gateway To Technology (GTT): these basic units program features a project-based curriculum designed to challenge and engage the natural curiosity and imagination of middle school students. This program includes seven units, of which Automation and Robotics (AR), Design and Modeling (DM), and Energy and Environment are considered the basic units in this program (Gateway To Technology | Middle School Engineering Program, 2013).

Automation and Robotics (AR): Students trace the history, development, and influence of automation and robotics. They learn about mechanical systems, energy transfer, machine automation and computer control systems. Students use a robust robotics platform to design, build and program a solution to solve an existing problem (Gateway To Technology | Middle School Engineering Program, 2103).

Design and Modeling (DM): In this unit, students begin to recognize the value of an engineering notebook to document and capture their ideas. They are introduced to and use the design process to solve problems and understand the influence that creative and innovative design has on our lives. Students use industry standard 3D modeling software to create a virtual image of their designs and produce a portfolio to showcase their creative solutions (Gateway To Technology | Middle School Engineering Program, 2013).

The Occupational Information Network (O*NET) is a job data program that is sponsored by the U.S. Department of Labor/Employment and Training Administration (USDOL/ETA) through a grant to the North Carolina Department of Commerce (O*Net Online, 2013).

Chapter 2: Literature Review

The purpose of this Chapter is to summarize the literature that is critical to the foundation of this study. The Chapter is organized into four sections which include: Critical Thinking, Critical-thinking instruments, Teaching Critical Thinking, and Project Lead The Way. The Critical-Thinking section presents definitions and theories related to critical thinking throughout history. The Critical-Thinking Instrument section presents comparisons between commercially available instruments of critical-thinking, appropriate for middle school age participants, including their theoretical dimensions and advantages and disadvantages of each one. The Teaching Critical Thinking section presents studies that displayed attempts and methods of teaching critical thinking during the last 50 years. Finally, the Project Lead The Way (PLTW) section included a survey of studies conducted on the PLTW middle and high school engineering programs during the last 10 years.

Critical Thinking

Facione (1990), while working under the auspices of the American Philosophical Association (APA), used a Delphi approach involving 46 experts to reach a consensus on definitions and categories of critical thinking. The definition of critical thinking that emerged from this process is "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." (p. 2). The report added the characteristics of a critical thinker:

> The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fairminded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters,

> diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit. (p. 2).

Facione, Facione, and Giancarlo (1996) indicated that for anybody to be an effective learner and a successful employee, one must be ready to make educated, reasonable judgments in partially vague settings about what to accept as true and what to do in a variety of circumstances. They identified seven attributions needed for such persons, “truth seeking, open-mindedness, systematicity, inquisitiveness, analyticity, cognitive maturity, critical thinking, self-confidence” (p. 71). Systematicity deals with organization, focus, and perseverance in thinking and drawing conclusions. Analyticity deals with alertness to potential problems, or difficulties, and the awareness for the need to intervene to solve them by using proof and purpose. Cognitive maturity refers to being wise and understanding when making decisions. It is the ability to see the complexity of the problem, to be flexible, and to look at the problem from different angles. It is the ability to be sensitive to different shades of circumstances and contexts. People with low cognitive maturity usually look at things as right or wrong bluntly, may make decisions too fast or too slowly, and are unwilling to change their mind.

There have been disagreements in the literature regarding the definition and theories related to critical thinking. Many other philosophers, psychologists, and/or educators defined critical thinking. There are some connections between all other definitions and theories, on one hand, and Facione’s APA definition and theories, on the other.

People began recognizing critical thinking during the times of Socrates, Plato, and Aristotle, whose main philosophical themes were to help students understand that things that happen around them mostly are not what they appear on the exterior (Burbach, Matkin, & Fritz, 2004). Interpretation and inference are two skills which are part of Facione's critical-thinking categories that have a meaning of critical thinking similar to those of Socrates, Plato, and Aristotle.

During the 20th century, critical thinking started getting more attention from educators. Dewey was one of the first people to define critical thinking during this century but his definitions focused on reflecting on a person's own thoughts (metacognition). He defines critical thinking as: "active, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it, and the further conclusions to which it tends." (Dewey & Skillbeck, 1970, p. 6). The APA definition included parts where the person reflects on his/her own thoughts by being fairminded in evaluation, and reasonable in the selection of criteria.

During the 1980's, critical thinking started to became increasingly important compared to previous eras (Dam & Volman, 2004). Sternberg (1985) defined critical thinking as "the mental processes, strategies, and representations people use to solve problems, make decisions and learn new concepts" (is cited in Splitter, 1990, p. 90). Another definition of critical thinking by Siegel (1980) is a "critical thinker is one who is appropriately moved by reasons: she has a propensity to believe and act in accordance with reasons; and she has the ability properly to assess the force of reasons in the context in which reasons play a role" (Siegel, quoted in Splitter, 1990, p 90). These two definitions form a good connection to Facione's definition and categories since making decisions and assessing the force of reason are similar to making judgments by using evidence.

Paul, who serves as the Director of the Center for Critical Thinking and Chair of the National Council for Excellence in Critical Thinking, defined critical thinking as "the art of analyzing and evaluating thinking with a view to improving it" (Paul & Elder, 2007, p. 4). They also added that critical thinking requires the person to be open-minded, mindful, able to solve problems, an effective communicator, and able to avoid looking at everything from the person's own point of view or that of his social group. These definitions and characteristics are similar to Facione's APA definition since this definition also includes analyzing and evaluating thinking skills. It also requires the person to be open-minded and trustful of reason.

Martin, D. (2011) wrote that Lipman believed that children at a young age can learn to think critically. Lipman developed and taught a course on critical thinking to middle school students. Many others were influenced by his work and tried his course successfully. His course resulted in significant improvement in middle school students' academic performance. Dr. Lipman defines critical thinking as "skillful, responsible thinking that facilitates good judgment because it relies upon criteria, self- correcting, and is sensitive to context." (Lipman, 1988, p.6).

Ennis (1987) defined critical thinking as "a reasonable reflective thinking that is focused on deciding what to believe and do" (p. 180). He additionally explained that this definition implies that someone characterized with critical thinking should be able to judge the credibility of sources; identify conclusions, reasons, and assumptions; judge the quality of an argument, including the acceptability of its reasons, assumptions, and evidence; develop and defend a position on an issue; and other skills (Ennis, 1987).

The two definitions by Lipman and Ennis focus on actions and judgments, which makes these definitions more operational and applicable than other definitions. At the same time, these definitions are very similar to Facione's APA definition since they discuss good judgment, criteria, and sensitivity to context, which are the bases of Facione's definition as well.

One can conclude at the end of this section that no matter what definition of critical thinking people understand and implement, what is important is that people are able to think and use their thinking to make wise judgments about things in which they are involved. It is the ability to be able to think and reflect on things happening around them and to be able to move beyond just memorization or listing of information especially in a continuously changing society. As a result, a critical thinker can succeed when dealing with people and in the workplace, and will become a good contributor to his/her society.

Critical-ihinking Instruments

Several critical-thinking instruments were described in the Mental Measurement Yearbook Database and have been summarized by Robert Ennis (1993). Almost all were designed for adults and/or high school students, which did not leave many choices for the researcher to use for the target age group for this study. Only two commercially available critical-thinking tests have been designed for middle school students and cover all dimensions of critical thinking: The California Critical Thinking Skills Test (CCTST) and the Cornell Critical Thinking Test (CCTT).

As displayed in Table 2, there are general similarities and differences between the two tests. The general purposes of both tests are similar. However, the population which the CCTST was designed for is middle school students, whereas the CCTT was designed for a broader population from grades 4 -14, which makes the researcher wonder how one can assess all age groups with many different abilities and experiences.

The conceptualization of the CCTST was based on the American Philosophical Association (APA) Delphi research where 46 experts gave their consensus on the dimensions and the definitions of critical thinking. One major definition that came out of this research for critical thinking was “a purposeful, reflective judgment to decide what to believe or what to do” (Insight Assessment, 2015, p. 14). On the other hand, the CCTT conceptualization was based on research conducted by Robert Ennis (1987) who defined critical thinking as “a reasonable reflective thinking that is focused on deciding what to believe and do" (p. 180).

The CCTST produces six subscale scores, each of which represents one of the dimensions of critical thinking. The CCTT, on the other hand, produces only a total score which does not show the multiple dimensions of critical thinking. When comparing the development of these two tests based on reviews in Mental Measurement Yearbook (Malcolm, 1985; & Hughes,1985) and test manual (Insight Assessment, 2015), one finds that the CCTST is not subject specific while the CCTT is more subject dependent. The CCTT follows a science fiction story format which displays a rescue mission to a planet and different scenarios are employed in each section of the test (Hughes, 1985). The test requires a significant amount of reading, which may indicate that the test measures reading comprehension rather than critical-thinking skills (Hughes, 1985).

Table 2

General Information California Versus Cornell

Feature	The California Critical Thinking Skills Test (CCTST)	Cornell Critical Thinking Test (CCTT)
Publisher	Insight Assessment-The California Academic Press LLC	Midwest Publications, Inc.
Purpose	Specifically designed to measure the skills dimension of critical thinking including analysis, inference, evaluation, induction, deduction, numeracy, and overall.	Assesses general critical thinking ability including induction, deduction, evaluation, observation, credibility, assumption identification, and meaning.
Population	Middle schools students: Grades 6 – 8	Grades 4 – 14. Level X
Conceptualization	Based on Delphi consensus conceptualization of critical thinking published by the American Philosophical Association in 1990	Based on Ennis's conceptualization of critical-thinking skills
# of Items-Format-Time limit	25 items-Multiple choices items-45 minutes or unlimited	71 items-Multiple choices items-50 minutes
Types of Scores	6: Analysis, Inference, Evaluation, Deductive Reasoning, Inductive Reasoning, Total Score	Total score only

The construct validity of the CCTST was supported by the CCTST pretest and posttest score improvement of college students who took a critical-thinking course (Lambert, 2007). On the other hand, the construct validity of the CCTT was verified by correlations with external criteria (Hughes, 1985). The external criteria that were used to validate construct validity do not provide a clear rationale about construct validity because the external criteria were based on using intelligence and reading comprehension measures which do not cover all critical-thinking skills dimensions (Hughes, 1985).

Criterion validity of CCTST was assessed by comparing CCTST scores to different measures of academic performance, such as grade point average with a correlation of 0.20, Graduate Record Examination (GRE) with a correlation of 0.72, and Scholastic Assessment Test (SAT) with a correlation of 0.41 (Lambert, 2007; Martin, 2007). CCTT criterion validity was not observed because the CCTT does not correlate with any other external measure, based on the manual (Hughes, 1985).

CCTST demonstrated satisfactory internal consistency through validation studies that were conducted on this instrument, but test-retest reliability was not discussed in the manual (Lambert, 2007). On the other hand, CCTT has demonstrated low internal consistency through a brief review of studies, but test-retest reliability was also not discussed in the manual.

Taube (1997) discussed the use of different critical-thinking skills and critical-thinking disposition instruments. The study indicated that it is more accurate to use both types of instruments, skills and disposition, to measure critical thinking than only using critical-thinking skills instruments. Frisby and Traffanstedt (2003) conducted a study on the relationship between the CCTST scores of high school and college students and the time taken to complete the test. The results showed that slower test takers obtained significantly higher scores on the CCTST.

Fawkers, O'mera, Weber, and Flage (2005) examined the content validity of the CCTST (the original adult version). Through careful investigation, they concluded that the test has a number of strengths and the clearest instructions when compared to other critical-thinking skills instruments. They also indicated that, even though most of the test questions were very well written and acceptable, a few questions had some errors and recommended that they be excluded from the test.

Research on the CCTT included research related to the characteristics of the test itself (Modjeski & Michael,1983; Frisby, 1992). Modjeski and Michael (1983) conducted a reliability and validity evaluation by a panel of psychologists of two critical-thinking tests, the CCTT and

Watson-Glaser Critical Thinking Appraisal. “Standards for Educational and Psychological Tests” were used in this evaluation and the results of the research indicated that both instruments ranked low according to these standards. Frisby (1992) conducted a study of construct validity and psychometric properties of the CCTT using three groups of college students which provided mixed and inconclusive results concerning the use of the CCTT as a critical-thinking skills instrument.

As a summary of both instruments, the CCTST was found to have better psychometric attributes than the CCTT. The use of many experts and from different fields in the CCTST development gives more creditability to the psychometric properties of the test than the CCTT, which was developed by one person. As explained in this section, the CCTST’s construct validity, criterion validity, and internal consistency are sound and more profound than the CCTT’s. The CCTST contains mostly question items that are not language dependent. On the other hand, the CCTT is heavily language dependent because it contains many unfamiliar words. Additionally, the CCTST was designed especially for the target age group for this study. Finally, the scoring that is provided by the CCTST is much better than the score produced by the CCTT since six dimensions of critical thinking are provided by the CCTST and only total score is provided by the CCTT.

Teaching Critical Thinking

Many attempts have been made to incorporate critical-thinking skills into K-12 schools and post-secondary formal educational experiences. Two approaches to the incorporation of critical-thinking skills include the creation of stand-alone critical-thinking courses and the modification of existing courses. Some attempts focused on incorporating critical thinking into the classroom utilizing hands-on activities, collaborative work, analyzing text, seminar questioning, journal writing, scaffolding, internet, etc. The following summarizes several attempts aimed at K-12 schools and post-secondary programs. The K-12 schools efforts involved integrating critical-thinking skills into the core subjects (e.g., mathematics, language arts, science, and social studies), or by using specialized curricula or technology courses/units specifically designed to promote critical-thinking skills.

The seminar questioning approach was used as a critical-thinking teaching method and proved to affect elementary and middle school students' critical-thinking skills and achievement scores positively. For example, Reid (2010) conducted a quasi-experimental research study to examine the impact of a critical-thinking program employing Socratic seminars, used in second grade classrooms in order to improve students' language arts test scores. The results of this study indicated that students who were exposed to the program had significant improvement on language arts test scores when compared to the control group.

Pogrow (2005) reported that a project called HOTS (Higher-Order Thinking Skills), supported by Title I grants, proved to be successful in promoting higher order and critical-thinking skills of elementary students. The main purpose of this program was to promote critical-thinking skills for disadvantaged and at-risk third grade students. Socratic questioning techniques, the promotion of new ideas, increased students' talk time, and decreased teacher talk time were some of the main techniques used by highly trained teachers. Students were given supplemental resources such as computers to help them come up with their own ideas. More than 26,000 schools around the country used the program which influenced the academic performance of over a million disadvantaged students positively.

Using an inquiry-based approach or hands-on activities to teach critical-thinking skills was another important teaching method that educators used. For example, Flick (1998) researched the use of the elements of inquiry in middle school classrooms. Teachers used a dynamic process called scaffolding by which the teacher adjusted instructions based on students' responses. The teachers who participated in the study acted as mentors to the students. Based on interactions between teachers and students, teachers have the choice of letting students use a computer, textbook, or laboratory materials in order to give the students the resources needed for them to succeed. This method appeared to help students develop critical- and cognitive-thinking skills that enabled them to solve problems and persevere in the task given to them based on a locally developed inventory behavior.

Esswein (2010) attempted to measure the impact that an inquiry-based middle school science professional development program delivered to teachers had on their students' critical thinking and reasoning abilities. The results of this research indicated that students whose teachers participated in the program had significantly higher reasoning abilities when comparing pretest and posttest results of science content tests, and a scientific reasoning ability measure. Additionally, a significant relationship between the teacher's scientific reasoning abilities scores and the posttest reasoning ability scores of her students was found.

Dindial (1990) redesigned science courses for first through fourth grade gifted students in order to include challenging activities through individual, small group, or large group activities. The activities, which included real-life experiences and the use of the scientific method, promoted critical-thinking skills. The study revealed positive results in student learning and critical-thinking skills as measured by worksheets about science content understanding and answers to higher order questions along with checklists for evaluating critical-thinking skills.

Using STEM-related curricula to promote critical thinking was another main method that educators used in K-12 schools. Duran and Sendag (2012) investigated the use of an Information

Technology (IT) program to develop critical-thinking skills in high school students within the STEM context. The study used a quasi-experimental design which revealed a significant improvement in the students' critical-thinking skills as measured by Test of Everyday Reasoning (TER). The study concluded that the IT/STEM experience that incorporates technology, inquiry, or real-life projects and collaborative work is beneficial in improving students' critical-thinking skills.

Mojica (2010), in a quasi-experimental study using a pretest-posttest control group design, found that there was no significant difference between two groups of middle school students taking enhanced technology units versus standard technology units. It is important to note that the study did not investigate the impact of technology units on students' critical-thinking skills, but it investigated the impact of supplemental math and science instruction on students' critical-thinking skills as measured by Cornell Critical Thinking Test.

Lammi (2011) conducted a quasi-experimental research study of high school students who were participating in an IT/STEM program by giving pairs of students an ill-defined engineering problem to solve. Data from administrating the "Test of Everyday Reasoning (TER) three times during a 10-month period on all participants suggested that students' involvement in STEM courses is effective in promoting their critical-thinking skills, such as thinking systematically, problem solving, inference, and communicating ideas.

Coleman, King, Ruth, & Stary (2001) conducted a research study that supported the use of a strategy to promote critical- and creative-thinking skills in fourth-grade classrooms. That strategy was the implementation of a teacher-made program called the "World Wide Web-Based Project" that gave students access to information and activities using the critical-thinking skills of application, analysis, synthesis, and evaluation. The results of this research were positive and in support of enhancing fourth-grade students' critical-thinking skills.

Using reflective or journal writing and communicating ideas constituted another approach that was used by educators to stimulate students' critical-thinking skills. Vojnovich (1997) examined the use of intervention strategies to motivate and improve critical-thinking skills of high school students. These results suggested that the use of a variety of critical-thinking tasks improved students' problem-solving skills . Simpson (2010) reported that using classroom-based research by integrating information and communication technology in a teacher-guided collaborative online context encouraged elementary students to become critical readers as measured by students reading assessments.

It is useful, at this point, to summarize all critical-thinking teaching and learning strategies that were the most useful in a K-12 context. The most effective K-12 critical-thinking teaching methods included: using seminar questioning techniques, project-based or active learning, journal or reflective writing, collaborative learning, web-based online tools, and STEM-related curriculum.

Post-secondary attempts to incorporate critical thinking into college students' course work were more systematic (following the scientific method) and subject-oriented than the attempts to incorporate critical thinking into K-12 schools. These attempts included several majors or areas of study such as Nursing and Business related fields. Nursing, as a profession, requires individuals with skills of clinical judgment, inference, problem-solving, and evaluation in order to succeed in their jobs. Studies utilized several methods to promote these skills such as the use of simulation, online instructional videos, case studies, technology-centered dynamic and cooperative learning assignments (Ousley, 2012; Popil, 2011; Mastrian & McGonigle, 1999).

The results of these studies suggested that these interventions had a positive impact on students' critical-thinking skills. Studies by Garvey and Buckley (2011) and David and Brown (2012) showed that the utilization of an application of prediction market technology, online material, video delivery methods, Excel and computer-based tasks showed positive impacts on the critical-thinking skills of students enrolled in business-related courses.

From all presented literature it appears that the most successful attempts to promote the teaching of critical-thinking teaching involved one or more of the following methods or strategies: inquiry-based learning, web-based technology tools integration, questioning techniques, writing in journals, online assignments, and most importantly teacher training. With this information in mind and attempting to connect it with the purpose of this study, Project Lead the Way (PLTW) curriculum, as defined in the introduction of this paper, includes these strategies which could suggest that PLTW may improve critical-thinking skills.

Project Lead The Way

The Project Lead The Way (PLTW) consists of five programs: Engineering, Biomedical, and Computer Sciences for high school students, Gateway to Technology for middle school students, and Launch for elementary school students (see Figure 2 for details) ("Our Programs", 2014). PLTW- Gateway to Technology (GTT) units are designed to help prepare middle school students for PLTW high school programs. Schools implementing the PLTW-GTT program are required per PLTW registration policies to start with the foundations units, then offer other units gradually as they deem appropriate because the participation in the foundation units gives the students the basic STEM background needed to complete the future STEM courses and units (PLTW Gateway - Curriculum.", 2014).

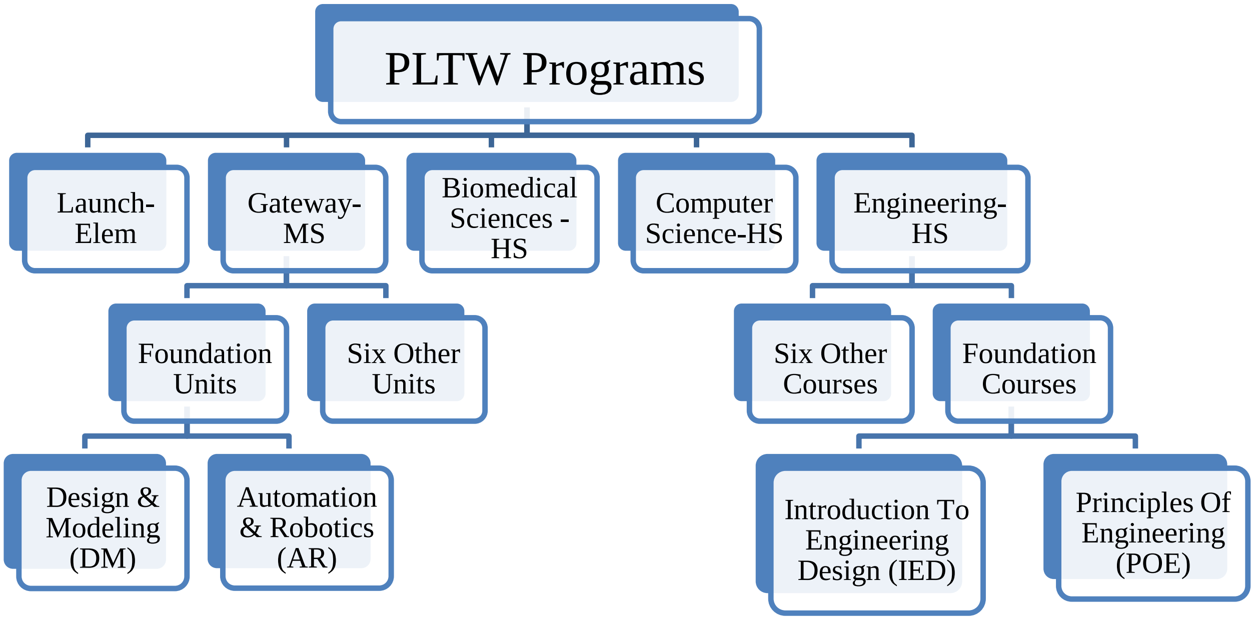

Figure 2: Project Lead The Way Program Detailed

Elem = elementary, HS = high school, MS = middle school

"Project Lead The Way's mission is to prepare students for the global economy. PLTW accomplishes this through world-class curriculum, high-quality professional development, and an engaged network" ("About PLTW", 2014).

Currently, PLTW is offered in all 50 states, and there are more than 5,800 school implementations with about 2,400 newly registered schools within the last three years (*Project Lead The Way, 2014)*. The significant growth of this program and the costs associated with it has led to the academic question as to whether PLTW is actually beneficial to students. For example, it is beneficial in increasing student achievement in math and science? What types of knowledge and skills are gained by students completing these courses? Are students who complete such courses better equipped with critical-thinking skills and problem-solving skills than other students? Moreover, university program administrators are interested in knowing how effective these classes are in getting students ready for STEM field careers.

Since this study involved the PLTW Gateway to Technology (GTT) program for the middle school, it was relevant to survey the studies related to the PLTW engineering and PLTW-GTT programs over the last 10 years. The published research studies about PLTW engineering programs in middle school (Gateway to Technology (GTT)) and high school (Pathway to Engineering (PTE)) programs related to student learning are presented in a table in Appendix G.

A significant body of research has been conducted about PLTW. Approximately, 50 percent of the documents produced from these studies were dissertations and the other 50 percent were reports, research papers, or conference proceedings. Dissertations are generally more reliable than funded reports by PLTW, since dissertations are more academically focused and tend to be less biased than other types of studies. The purposes for administering these studies included: math and science achievement, STEM career interest, STEM-related fields' college enrollment, advanced math and science course enrollment, and persistence in college and STEM careers.

Most of PLTW research studies focused on high school engineering program. One study by the University of Wisconsin-Milwaukee (2011) on PLTW courses lacked internal validity based on the formulation of the survey questions. Tran & Nathan (2010, p. 143) reported that there was no relationship between student achievement on state standardized tests and the completion of a PLTW high school Introduction to Engineering Design course. The Iowa Department of Education longitudinal study used students who moved from eighth grade to high school. PLTW students served as the treatment group and a non-PLTW group of students constituted the control group. The study concluded that students enrolled in PLTW had little or moderate growth in their achievement scores when compared to the control group. Additionally, the results of the study revealed that most students were white males and from the top upper-quartile. Therefore, the researchers suggested a future study that will account for the selection process for those taking PLTW courses where pre-existing abilities of students have an effect on their achievement (Schenk, Rethwisch, Chapman, Laanan, Starobin, & Zhang, 2011, p. 27).

Schenk, Rethwisch, Chapman, Laanan, Starobin, & Zhang (2011) conducted a study to test the impact of the PLTW high school engineering program on students' performances and future college enrollment. The study indicated that students enrolled in the program had moderate gains in mathematics standardized test scores and a smaller increase in science scores. Additionally, it was found that the students enrolled in PLTW programs had a 37 percent higher chance of enrolling in college, especially 2-year colleges.

A longitudinal study by Starobin, Schenk, Laanan, Rethwisch, and Moeller (2013), conducted on students who participated in PLTW courses during high school, indicated that PLTW students are more likely to pursue a college degree after graduating from high school. Additionally, the study showed that these students are ten percent more likely to pursue a college degree in STEM fields than non-PLTW students. These above mentioned studies and others (Paslov, 2006; Wheeler, 2009; & Martin, 2011) focused on student achievement and did not address the students' critical-thinking skills, which will be the concentration of this study. Additionally, these studies focused primarily on high school students, whereas this study will focus on middle school students.

A recent longitudinal study by Overschelde (2013), indicated that high school students who enrolled in PLTW program performed significantly higher on the Grade 11 Texas mathematics assessment, a higher percentage met the college-ready criterion, a higher percentage enrolled in Texas higher education institutions, and the non-college-bound PLTW students earned higher wages.

Salzman, Mann, & Ohland (2012) attempted to determine the long-term effect of PLTW course completion on students' future perceptions and motivation to enroll in colleges of engineering. The study revealed that PLTW students had positive long-term perceptions of engineering; at the same time, participants thought that it helped them succeed in their engineering studies. It is important to note that most participants in the study were white males. The study suggested that further research studies are needed for the results to be generalizable (p. 8).

Several studies have been conducted in the state of Indiana about the perceptions of principals, teachers, and parents on PLTW courses (Shields, 2007; Rogers, 2006 & 2007; Werner, &, Kelly, 2008). These studies did not address middle school students' critical-thinking skills; instead, they addressed the perceptions of other people who were involved in the students' learning process and primarily targeted high school PLTW courses. Therefore, there is a lack of valid and reliable research regarding the impacts of PLTW experiences on middle school students' critical-thinking skills, which this study addressed.

The impact of PLTW program on problem solving and thinking skills was only investigated in three studies which were not conducted on the PLTW middle school program (Kelley, 2008; Kelley, Brenner, & Pieper, 2010; Lammi, 2011). Kelley (2008) conducted a comparative study to investigate the cognitive process of high school students who participated in two different STEM programs [i.e., PLTW and National Center for Engineering and Technology Education (NCETE)]. The results of the study revealed that PLTW participants used problem definition and analysis skills more than participants of the other program. While the NCETE program participants spent more time on designing and generating solutions.

A study by Kelley, Brenner, and Pieper (2010) examined two approaches to engineering design – Project Lead The Way (PLTW) and Engineering Projects in Community Service (EPCS) – using a mix of qualitative and quantitative methods. This study used a pre-defined cognitive-skills inventory and analyzed which inventories the students used the most while solving engineering problems. The pre-defined cognitive-skills inventory was based on an earlier study by Halfin (1973) that identified 17 universal mental processes, some of which included: analyzing, computing, designing, defining problems, interpreting data, managing, predicting results, and questioning. These are consistent with critical-thinking categories identified by the Delphi research. The results of this study revealed that students in both approaches to engineering programs (i.e., PLTW and EPCS) used ten out of 17 cognitive skills while solving an engineering problem.

Lammi (2011) administered a study involving PLTW high school program participants to investigate the students' system thinking using specific dimensions when engaged in an engineering design challenge. The results of this study indicated that students used higher-order thinking skills (i.e., analysis, evaluation, and synthesis) when engaged in solving an engineering design challenge. It also indicated the use of optimizations, unboundedness, and sketching while solving the given engineering challenge. As one can see from the literature, there is little work investigating the critical-thinking skills of middle school students. Therefore, this study will address the role of selected STEM programs on critical-thinking skills.

Chapter 3: Methodology

This chapter presents the methodology of this study, which includes the research design, the population and sample, a description of the treatments, the instrument characteristics, along with the data collection, and data analysis procedures. A quasi-experimental research design was used for this study. This type of research attempts to determine whether there is an impact on the dependent variable by the treatment. A control group was used to help ensure that the treatment was the primary impact on the dependent variable, and there is a true difference between experimental and control groups when the independent variable is manipulated, which results in differences between dependent variables (Mertler & Charles, 2011). In this pretest-posttest control group quasi-experimental research, the researcher attempted to determine the impact of the completion of each of the PLTW-Gateway to Technology (GTT) foundation units (treatment) on students' critical-thinking skills. Critical-thinking skills were measured using the middle school version of the California Critical Thinking Skills Test (CCTST-M25).

Research Design

A comprehensive literature review focusing on critical thinking and technology and engineering education was conducted to select a critical-thinking instrument. The California Critical Thinking Skills Test (CCTST) was chosen based on its strong psychometric properties.

An appropriate population for the study was selected based on several factors (as discussed in the next section). Sixth grade students who were enrolled in the PLTW-GTT Design and Modeling (DM) unit constituted the treatment group; and students in the same grade who were not enrolled in that unit, with similar characteristics as the treatment group, constituted the control group. Seventh-grade students who were enrolled in the PLTW-GTT Automation and Robotics (AR) unit constituted the treatment group; and students in the same grade who were not enrolled in that unit, with similar characteristics as the treatment group, constituted the control group.

Each group, including the treatment and control groups, were administered the CCTST along with the demographic questions once at the beginning of the treatment, and a second time at the end of the treatment. The data were collected, and then the responses were matched for each participant between pretest and posttest. A detailed analysis was conducted on all data including demographic variables and the CCTST scores and sub-scores, before the results and conclusions of the study were finalized. Figure 3 identifies the key steps used in conducting this research.

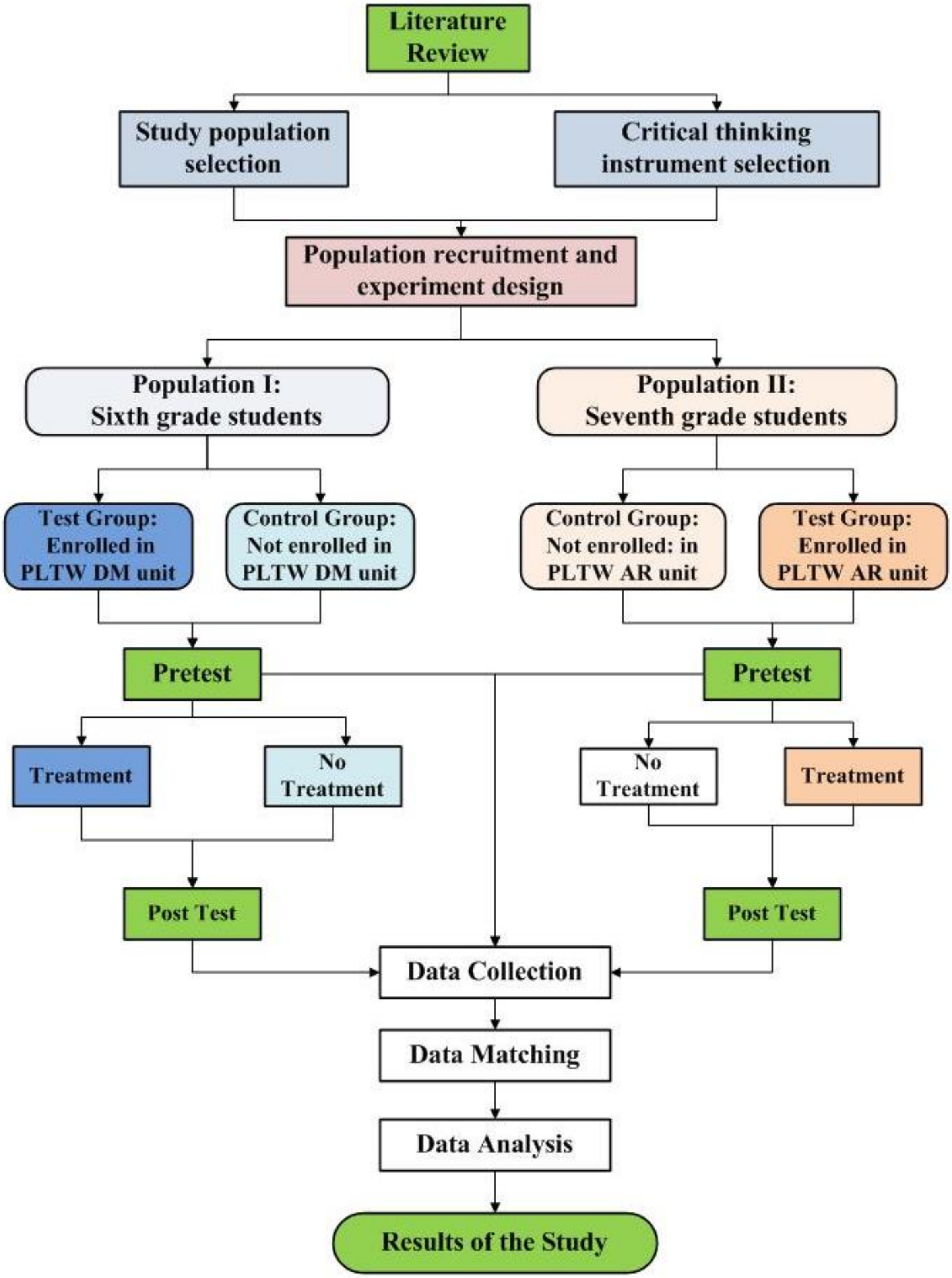

Figure 2: Research Design

Population and Sample

The population for this research study included sixth- and seventh-graders from a Michigan suburban middle school located in the southeastern part of the state. The school was selected for this study based on several important criteria. The first criterion was that the school/s must have implemented a PLTW-GTT foundation program for at least three years and the teacher must have at least three years of experience in delivering the program. The second criterion was that the school did not offer any competing STEM stand-alone programs.

The researcher identified several schools that fulfilled the given criteria with help from the PLTW affiliate director in Michigan who had access to the national PLTW database which includes all PLTW schools, the number of years of implementation and the level of the PLTW teachers' experience. Three middle schools in Michigan, two suburban and one urban, who met the mentioned criteria, were contacted by the researcher and the dissertation advisor. The school district superintendent for each school was contacted by email, and by phone. Only one of the three superintendents of the three schools agreed to participate in the research. The principal of the approved suburban middle school was contacted by email and he agreed to and supported having his school participate in the study as well. The school principal and the PLTW teachers met with the researcher and research advisor to discuss the logistics of the research.

The sample for this research study was selected from sixth- and seventh-graders. Similar to overall school characteristics, approximately 90 percent of the sample was White while three percent were African American, and three percent were Hispanic. Middle school students in the State of Michigan, on average, are 69 percent White, 18 percent African American, and 7 percent Hispanic. It is clear from this comparison that there was a difference in the ratios of the number of African-American and White students between the school selected and the state as a whole, as highlighted in Table 3. Based on the PLTW implementations that existed at the time of this study, schools that more closely resembled the state ratios could not meet the criteria regarding experience with PLTW GTT Foundation modules.

Table 3

Ethnicity: Sample School vs. Michigan

Race	School	Michigan
American Indian	0%	1%
African American	3%	17%
Asian or Pacific Islander	2%	3%
Hispanic of Any Race	3%	7%
Native Hawaiian	0%	0%
Two or More Races	2%	3%
White	90%	69%
Total Number of Students	767	230,899

Approximately 49 percent of the selected middle school students were female and 20 percent of students were from low-income families. In comparison, an average of 49 percent of Michigan middle school students were female and 49 percent of students were economically disadvantaged. It is clear that the participating school had a similar male-to-female student ratio as the state. On the other hand, the school had a much smaller percentage of economically disadvantaged students than the state, as highlighted in Table 4.

Table 4: Demographics

Demographics: School vs. Michigan Sixth- & Seventh- Grades

Demographic	School	Michigan
Males	51%	51%
Females	49%	49%
Economically Disadvantaged	20%	49%
English Language Learners	< 5%	< 5%
Students with Disabilities	9%	13%
Total Number of Students	767	230,899

On the 2013 Michigan Educational Assessment Program (MEAP) tests, sixth graders at the participating school passed the MEAP tests at a rate that was 17 percent higher in mathematics and 10 percent higher in reading than their Michigan peers. Please refer to Table 5 for details (State of Michigan, 2013)

Table 5:

Passing Rates: Sixth Grade MEAP

Subject	School	Michigan
Mathematics	59.10%	41.50%
Reading	81.50%	71.50%
Average	70.30%	56.50%

Similarly, seventh graders at the participating school passed the MEAP tests at a rate that was 16 percent higher on the mathematics MEAP test and 14 percent higher on the reading MEAP test than their Michigan peers. Refer to Table 6 for details (State of Michigan, 2013).

Table 6

Passing Rates: Seventh Grade MEAP

Subject	School	Michigan
Mathematics	54.50%	39.20%
Reading	73.80%	60.40%
Average	64.15%	49.80%

Initially, four groups were selected from the middle school to participate in the study at the beginning of the Fall semester of 2014. These groups included: 150 sixth grade students enrolled in PLTW-GTT-Design and Modeling (PLTW-DM) unit, and a similar comparable control group of 60 sixth grade students not enrolled in any PLTW unit; and a group of 180 seventh grade students enrolled in PLTW-GTT-Automation and Robotics (PLTW-AR) unit, and a similar comparable control group of 60 seventh grade students not enrolled in any PLTW unit. Teachers distributed the assent (students) and consent forms (parents) to complete. It is typical in research efforts like this for some attrition to occur. The actual numbers of participants in each group who were considered in the results of this study are listed in the data collection section. A description of the process used for collecting data, matching pretest-posttest scores, and analyzing the results are presented as well. The researcher was careful when attempting to generalize the results of this study to other middle schools. The results of this study only can be generalized to schools with similar demographic characteristics.

Treatments

The PLTW-GTT Design and Modeling (DM) and Automation and Robotics (AR) units are the two treatments used in this study. Each of these units promotes certain science, technology, and engineering standards. As described by PLTW (Gateway - Curriculum 2014), students in the Design and Modeling (DM) unit learn to apply the design process to solve real life problems and incorporate creative and innovation thinking in their lives. As teams, they design several products such as a playground and furniture, then communicate their ideas by hand in their engineering notebook, then use Autodesk design software to convert these designs into plans and virtual images, and produce portfolios to showcase their creative products.

The PLTW (Gateway - Curriculum 2014) description reveals that the Automation and Robotics (AR) unit helps students understand the history, development, and benefits of automation and robotics as they study motorized systems, energy transmission, engine automation, and computer switch platform. Students use the VEX Robotics systems to design, build, and program real-life machines such as traffic lights, toll stands, and robotic arms.

Instrumentation

The instrument was an online test that consisted of two parts – the California Critical Thinking Skills Test (CCTST) and a set of demographic questions – that were administered to both the treatment and the control groups before and after treatment. The CCTST was used since it was designed to measure the students' critical-thinking skills. The purpose of collecting demographic data was to understand the background of participants, enable comparisons between categories of respondents, rule out previous differences between groups, try to measure whether correlation between variables existed, and suggest future studies.

Demographic section. The demographic questions were developed based on demographic variables thought to be relevant and available, which included *age*, *sex*, *ethnicity*, *socioeconomic status*, *parents' degrees*, and *parents' jobs*. Four additional questions sought information about the level of support provided by parents while students worked on assignments, the student's *Usual Science Grade* and *Usual Math Grade*, and the *future career interests of the student* (the demographic questions are displayed in Appendix E). Finally, *MEAP* results were also provided by the school administration. The dissertation committee members were involved in the review of the demographic questions and provided suggestions.

Critical thinking measure. The middle school version of the *"California Critical Thinking Skills Test"* (CCTST-M25) was chosen based on a literature review and reviews provided in the “Mental Measurement Year Book” (Lambert, 2007; Martin, 2007; Malcolm, 1985; & Hughes, 1985). Contact with the publisher of this instrument was made to identify the types of instruments available for grades 6 – 8. Two instruments were identified by the publisher’s contact person that are designed for middle school students, the “California Critical Thinking Skills Test-Form M25” (CCTST-M25) and the “California Measure of Mental Motivation” (CM3-L2). The CCTST-M25 was found to align with the purposes of this research better than the CM-L2 since the CCTST-M25’s main purpose was to measure critical thinking, while the purpose of the CM3-L2 was to measure the motivation level of thinking.

The CCTST M-Series Manual 2015 describes the content validity of the CCTST as being sound because it was based on a comprehensive Delphi Panel effort conducted by the the American Philosophical Association. Forty-six experts from relevant fields participated in this Delphi effort. The CCTST consists of 25 questions where each question stem contains a short everyday life scenario. Each question stem includes all the information needed to answer the question correctly by forming reasonable judgments based on the scenarios. The questions do not measure content knowledge; rather, they only measure critical-thinking skills which “make it possible to use this instrument as a pretest and posttest to measure improvement in critical thinking that occurs during any education program (or intervention).” (Insight Assessment, 2015, P. 60).

Construct validity is typically verified by correlational studies where the test is correlated with other measures that include the construct. There is high correlation between the CCTST and the standardized tests of college-level readiness, which has been shown through a number of studies (Insight Assessment, 2015). The CCTST provides an overall score, percentile score, and six other sub-scores. The subscale scores include: analysis, inference, evaluation, induction, deduction, and numeracy. The evidence of the construct validity that appeared to be inherent in the Delphi process used by the APA effort, the CCTST-M25 was deemed to be the best choice for this research.

To understand the CCTST scores in Chapters four and five, it is important to understand the six dimensions of the CCTST: Analysis, Inference, Evaluation, Induction, Deduction, and Numeracy. According to the (Insight Assessment, 2015), analysis is a skill that “enables people to identify assumptions, reasons, claims, and to examine how they interact in the formation of arguments.” “Inferences skills enable us to draw conclusions from reasons and evidence”. Evaluation enables the person to “assess the credibility of sources of information and the claims they make”. Induction is the ability to make decisions in contexts of uncertainty. Deduction is the ability to make decisions to precisely define contexts where rules, conditions, core beliefs, values, policies, principles, procedures, and terminology completely determines the outcome. Numeracy is the capability to solve quantitative problems and to make reasonable judgments resulting from quantifiable information in different contexts.

It is important to note that the minimum possible score for the CCTST overall or any of its six subscale scores is 60 and the maximum possible score is 100 (Insight Assessment, 2015). In other words, the scores run over a 40-point span and not over a 100-point span.

Pilot testing. In order to determine the perceived readability and the time-limit appropriateness of CCTST for this age group, the researcher administered only the CCTST portion to three middle school students. The average time it took for the students to complete the test was 37 minutes, which was less than the publisher’s suggested time limit of 45 minutes (Insight Assessment, 2015). A quick interview with all pilot test participants indicated that the vocabulary used on the test was known to all and the complexity of the questions were reasonable. Overall, all pilot test participants felt that the test time limit was fine.

The CCTST can be administered online with an option of adding demographic questions to it. Therefore, to facilitate the data collection, the demographic questions were embedded at the beginning of the CCTST, which allowed both parts of the test to be administered sequentially. In order to check again for the time limit of the test, including the demographic questions this time, the researcher administered a second pilot test to four students during the summer of 2014. The students who were chosen to take the pilot test were going into sixth- and seventh-grades in order to match the age and grade level of the participants who were going to be tested in the fall of 2014.

Two females and one male were entering the sixth grade, and one male was entering the seventh grade. The researcher noticed that two out of four pilot students did not know about their parents' education during the time when they were answering the demographic questions. Based on this note, the researcher informed the teachers to make sure that the participating students in the actual study asked their parents about their education prior to taking the test. The average time it took the students to complete their test was 31 minutes, which is less than the suggested time by the publisher (45 minutes). These students' MEAP reading levels ranged from Low Proficient to Advanced levels. All except one student felt comfortable with the time limit for the test. While conducting an interview with the mother of that student, she indicated that her son frequently needs extra time to complete his assignments in school.

Human subjects' approval.

Human Subject Application Form was submitted to EMU's human subject review committee, including consent and assent forms, after the dissertation proposal was approved by the dissertation committee.

Data Collection

The data were collected using one online test that included both the demographic questions and the CCTST scores. Additional information about the test administration was provided as part of the CCTST results which were the number of minutes needed to complete the test for each student and the percentage of those completing the complete test. Table 7 summarizes the groups and the details of their participation.

Table 7

Groups and Tests

Group	Pretest (September)	Posttest (January)
Treatment Group – Design & Modeling	✓	✓
Control Group – matched with Design & Modeling	✓	✓
Treatment Group – Automation & Robotics	✓	✓
Control Group – matched with Automation & Robotics	✓	✓

The CCTST pretest was administered between the dates of September 18 and September 30, 2014 to those students who provided signed assent and consent forms. The posttest was administered between January 8 and January 30, 2015. Before the pretest, each student was assigned a Student ID by the researcher to enable paired comparisons between the results of the pretest and the posttest. The CCTST test for both DM and AR groups were administered by two different PLTW teachers in the school. Additionally, the treatments were delivered or taught to

DM or AR groups by these two teachers. The two teachers had different number of years of experience in teaching the PLTW units and in teaching prior to teaching PLTW.

Only the results of students who participated in both the pre- and posttests were analyzed since the purpose of this study was to check the impact of the PLTW treatment on the students after completing it. Therefore, the results of those students who participated in only the pretest without participating in the posttest were not considered in the analysis.

Unfortunately, there were some inconsistencies when the students entered their IDs, which made it difficult to find a match between each student's pre- and post-test results. In cases where the ID was not entered correctly, the researcher was able in many cases to match the results by matching other respondent demographic variables. The researcher additionally eliminated some of the results that did not meet the test administration criteria based on the CCTST manual (Insight Assessment, 2015). Specifically, the results of students who took 15 minutes or less to complete either test [i.e., Pre-testing and/or Post-testing] and those who answered less than 60 percent of the questions were eliminated from the analyses.

One hundred fifty sixth grade students who were enrolled in PLTW-GTT-Design and Modeling (PLTW-DM) unit, and a similar comparable control group of 60 sixth grade students not enrolled in any PLTW unit were originally targeted for this study. Seventy-nine of the PLTW-DM treatment group were able to participate in the pretest, and 72 students were able to participate in the posttest of whom only 63 met the CCTST administration criteria. Thirty-one of the DM Control group were able to participate in the pretest, and 31 students were able to participate in the posttest of whom only 28 met the CCTST administration criteria.

One hundred eighty seventh grade students who were enrolled in the PLTW-GTT-Automation and Robotics (PLTW-AR) unit, and a similar comparable control group of 60 seventh grade students not enrolled in any PLTW unit were targeted for this study. Fifty-nine of the PLTW-AR treatment group were able to participate in the pretest, and 42 students were able to participate in the posttest of whom only 27 met the CCTST administration criteria. Thirty-three students from the AR Control group were able to participate in the pretest, and 20 students were able to participate in the posttest of whom only 18 students met the CCTST administration criteria.

Table 8 summarizes the number of participants for each group at each stage. The final count of participants whose scores were used in the results and the analysis of this study: 64 participants in the DM-Treatment group, 28 in the DM-Control group, 27 in the AR-Treatment group, and 19 in the AR-Control group.

Table 8

Research Participation

Group	Total Targeted	Total Pretests	Total Posttests	Total Invalid	Total Valid
DM Treatment - 6th Grade	150	79	72	9	63
DM Control - 6th Grade	60	31	31	3	28
AR Treatment - 7th Grade	180	59	42	15	27
AR Control - 7th Grade	60	33	20	2	19

Data Analysis

The demographic data, included age, sex, ethnicity, socioeconomic status, parents' degrees, parents' help to student, and *Usual Science Grades* and *Usual Math Grades*, were analyzed using measures of central tendency, normality, and deviation. The parents' jobs and the student's future career interests were open-ended questions that were analyzed using qualitative methods by finding themes and patterns. The analysis of the demographic data helped present a full description of the participants of the study and provided guidance in selecting the appropriate statistical tool for inferential analyses.

The CCTST produces several scores which include the overall score, the percentile score, and the six sub-scores. The CCTST scores were analyzed using both descriptive statistics such as means, deviations, normality, and skewedness, and inferential statistics such as the t-test, to test each hypothesis statement. Comparisons of improvement scores between treatment and control groups were made as well. Also, the two scores related to test administration, the number of minutes spent on taking the test, and the percentage of the completion of the CCTST were analyzed to rule out any problems with test administration. For example, one student only spent one minute on the test. Another student completed only 10% of the test. Such cases were removed from the data analyses because these test administrations did not meet the publisher's recommendations for the test administration (Insight Assessment, 2015).

The CCTST gain scores of the treatment and control groups were compared to test the first and the second null hypotheses. For each group, treatment and control pairs, mean overall and subscale gain score were compared. A Paired Samples Test was used to test for significant differences between the CCTST pre and post scores for the two groups. When a difference in these scores between both groups, treatment and control groups, was found to be significant with a P-value of 0.05, then the null hypothesis was rejected. On the other hand, when the difference of these scores was found to not be significant then there was a failure to reject the null hypothesis.

To test the third and the fourth null hypotheses, the treatment group CCTST mean scores of males were compared with the mean scores of females using an independent t-test. If the posttest scores between the two comparison groups were found to be significant, with a P-value of 0.05 or less, then the null hypothesis was rejected. If, on the other hand, the difference between these scores was found to be not significant then there was a failure to reject the null hypothesis since the difference between the two sets of data was not significant.

The fifth null hypothesis was tested using Correlation-Bivariate analysis. A correlation analysis was conducted between the overall CCTST posttest and the demographic variables. In cases where a significant correlation, with a *P-value* of 0.05 or less, was found between the overall CCTST posttest and a demographic variable, the null hypothesis was rejected for that demographic variable. If, on the other hand, the correlation between the overall CCTST scores and a demographic variable was found to not be significant, then there was a failure to reject the null of that demographic variable. Since the demographic variables are categorical, there was a need to code each of them to be able to calculate the correlation tables for each one. Table 9 shows the coding that was used in calculating the correlation tables.

Table 9

Categorical Variables Coding

Demographic Variable	Category	Code
Sex	Male	0
	Female	1
Socioeconomic status	Pay the full lunch price	0
	Qualify for reduced lunch	1
	Qualify for free lunch	2
Student Future Career Interest	Non STEM Related Career	0
	STEM Related Careers	1
Parent Education	Unknown	0
	High school diploma or less	1
	2-year diploma	2
	4-year Bachelor’s degree	3
	Master's degree	4
	PhD degree	5
Parent Job	Non STEM Related Career	0
	STEM Related Careers	1
Parent's help in HW	No	0

	Sometimes	1
	Yes	2
Usual Science/Math Grade	F	1
	D	2
	C	3
	B	4
	A	5

Summary

This study used quasi-experimental research methods to determine the impact of PLTW Gateway to Technology units' completion on middle school students' critical-thinking skills. Students from the sixth- grade and seventh-grade participated in the study from which the treatment groups and the control groups were extracted. The treatment in each case was completing one of the PLTW-GTT foundations unit, either Design and Modeling (DM) or Automation and Robotics (AR). Students in treatment and control groups took a critical thinking test (CCTST) before and after treatment along with a demographic set of questions.

The data were then reorganized through the matching of pretest and posttest scores. Any participant result that did not meet the test administration criteria was eliminated. All results were combined in one single file to prepare the data to be entered into the SPSS. Finally, all the data were analyzed using descriptive and inferential analysis methods which are presented in the next chapter.

Chapter 4: Results

The primary purpose of this study is to determine whether participants' completion of a PLTW GTT foundation unit affect students' critical-thinking skills as measured by the California Critical Thinking Skills Test (CCTST) when compared to students who do not complete a GTT foundation unit. This chapter is divided into four sections and presents the results of the data analysis that were used to describe the sample and respond to the research questions listed in Chapter One. The first section provides a description and characteristics of the participants using descriptive data such as measures of central tendency, normality, and variability. The second section provides selected descriptive statistics of the CCTST overall and sub category scores. The third section presents the results of the inferential statistical analysis to test each hypothesis. Finally, an overall summary of the results is provided.

The results displayed in this chapter and described in the final chapter only include the actual valid participants of this study. Valid participants are those who took the Pretest, Posttest, and met the criteria of the test administration based on the CCTST M-Series Manual 2015 (Insight Assessment, 2015). Any participants who did not meet these three conditions were eliminated from the analysis. The details of the process of finalizing the actual valid participants were presented in Chapter 3 in the Data Collection section.

All information used in this chapter was gathered through the use of an online instrument which included two parts: part one addressed the demographic questions (Demographic questions are included in Appendix E) and part two consisted of the CCTST (the description of the CCTST is included in Appendix F). The purpose of collecting demographic data was to understand the background of the participants, enable comparisons between categories of respondents, to find any correlations between variables if any, provide a better understanding of CCTST results and as a basis for suggesting future studies.

Description and Characteristics of Participants

Four groups of participants from the middle school completed the CCTST along with the demographic questions at the beginning of the 2014 Fall semester. The number of participants in each group included: 63 sixth grade participants enrolled in PLTW-GTT-Design and Modeling (PLTW-DM) unit, and a similar comparable control group of 28 sixth grade participants who were not enrolled in any a PLTW unit; and a group of 27 seventh grade participants who were enrolled in a PLTW-GTT-Automation and Robotics (PLTW-AR) unit, and a similar comparable control group of 19 seventh grade participants not enrolled in any PLTW unit. Table 9 summarizes this information.

Table 10

Research Valid Participants

Group	# of valid Participants
DM Treatment - 6th Grade	63
DM Control - 6th Grade	28
AR Treatment - 7th Grade	27
AR Control - 7th Grade	19

The demographic questions addressed the following categories: sex, age, ethnicity, socioeconomic status, parents' education, parents' job, level of parents' help in homework to participants, the *Usual Science Grade*, the *Usual Math Grade*, and the participant's "Future Career Interest". Please note that all participants provided demographic information twice: with the pretest and the posttest as described in chapter three. This helped ensure consistency in the demographic information entry by each participant. In cases where there was an inconsistency between the pretest and posttest entries for a participant, the researcher made a judgment to choose the participant's response that was most consistent with the responses to the other demographic variables. Note that all displayed demographic results in this chapter are taken from the posttest administration of the demographic questions.

Sex. The distribution of female participants was relatively consistent from group to group as shown in Table 11. Slightly more than half of DM Treatment group participants were female, while slightly less than half of DM Control group participants were female. The AR Treatment group was balanced while the AR Control group had more males than females.

Table 11

Frequency Distribution: Sex

Sex	Group Name			
	DM Treatment	DM Control	AR Treatment	AR Control
Male	28 (44%)	15 (54%)	13 (48%)	11 (57%)
Female	35 56%)	13 (46%)	14 (52%)	8 (42%)
Total	63 (100%)	28 (100%)	27 (100%)	19 (100%)

Age. Forty seven of the 63 DM Treatment group participants (75 percent) were 11-years old and the rest were 12-years old. Fourteen of the 27 AR Treatment group participants (52 percent) were 12 years old, while twelve were 13-years old (44 percent), and one was 14 years old at the conclusion of the study. Twelve of the 19 AR Control group participants (63 percent) were 12 years old while seven (37 percent) were 13 years old. In other words, the ages of all participants were within their grade level norms. As shown in Table 12 includes the details.

Table 12

Frequency Distribution: Age at the time of the Posttest

Age	Group Name			
	DM Treatment	DM Control	AR Treatment	AR Control
11	47 (75%)	18 (64%)		
12	16 (25%)	10 (36%	14 (52%)	12 (63%)
13			12 (44%)	7 (37%)
14			1 (4%)	
Total	63 (100%)	28 (100%)	27 (100%)	19 (100%)

Ethnicity. To acquire information about ethnicity, the participants were asked to self-select one of six ethnicity choices which are listed in the first column of Table 13. The majority of participants in all four groups were "White, Caucasian, or Anglo American". Very few (three to seven) from each group identified themselves as being from "Hispanic, Latino, Mexican American" or "Asian, Asian American, Pacific Islander" ethnicities. The rest of the participants either chose not to provide this information or selected "other" as a response to this item. Table 13 summarizes ethnic backgrounds of each group of participants.

Table 13

Frequency Distribution: Ethnicity

Ethnicity	DM Treatment	DM Control	AR Treatment	AR Control
Didn't provide this information/Other	3 (5%)	8 (29%)	3 (11%)	1 (5%)
White, Caucasian, Anglo American	53 (84%)	16 (57%)	21 (78%)	15 (79%)
Asian, Asian American, Pacific Islander	1 (2%)	2 (7%)	1 (4%)	0 (0%)
Hispanic, Latino, Mexican American	2 (3%)	0 (0%)	2 (7%)	1 (5%)
Black, African American				
American Indian, Native American	4 (6%)	2 (7%)	0 (0%)	2 (1%)
Total	63 (100%)	28 (100%)	27 (100%)	19 (100%)

Socioeconomic status. The question regarding socioeconomic status requested participants to self-select what best describes them from a list of three choices: 1) I do not qualify for free or reduced lunch, 2) I qualify for reduced lunch, and 3) I qualify for free lunch. Fourteen out of 63 participants (or 23 percent) of the DM Treatment group and 6 out of 28 participants (or 22 percent) of the comparable control group were economically disadvantaged. Six out of 27 (or 23 percent) of the AR Treatment group and 4 out of 19 (21 percent) of the comparable control group were economically disadvantaged. The ratios of economically disadvantaged to non-economically disadvantaged participants who qualify for reduced or free lunch, were similar in all four groups which was approximately 22 percent of each group. Table 14 displays the details of the socioeconomic status of all groups' participants. This percent was close to the school's sixth- and seventh-grade percent of economically disadvantaged students.

Table 14

Frequency Distribution: Socio Economic Status

Status	Group Name			
	DM Treatment Group	DM Control Group	AR Treatment Group	AR Control Group
I do not qualify for free or reduced lunch	49 (78%)	22 (79%)	21 (78%)	15 (79%)
I qualify for reduced lunch	1 (2%)	3 (11%)	1 (4%)	1 (5%)
I qualify for free lunch	13 (21%)	3 (11%)	5 (19%)	3 (16%)
Total	63 (100%)	28 (100%)	27 (100%)	19 (100%)

Parents' education. The questions related to the parents' education provided a choice to self-select the highest level of their primary and the second parents' education from five different levels of education: High school diploma or less, 2-year diploma, 4-year Bachelor's, Master's degree, and PhD degree. An additional "Unknown" choice was provided as well to provide an option for those participants who have only one parent/caregiver. As shown in Table 15, 45 (72 percent) of the 63 DM Treatment group "first parents" reported to have held at least a 4-year bachelor's degree or higher with 25 (40 percent) holding a master's degree or higher. Twenty-two of the 28 DM Control group parents (79 percent) were reported holding a 4-year bachelor's degree or higher with 17 of them holding a master's degree or higher.

Table 15

Frequency Distribution: Parent Degree - DM

Degree	First Parent Degree		Second Parent Degree	
	DM Treatment Group	DM Control Group	DM Treatment Group	DM Control Group
Unknown			2 (3%)	2 (7%)
High school diploma or less	8 (13%)	2 (7%)	19 (30%)	9 (32%)
2-year diploma	10 (16%)	4 (14%)	6 (10%)	3 (11%)
4-year Bachelor's degree	20 (32%)	5 (18%)	17 (27%)	8 (29%)
Master's degree	24 (38%)	17 (61%)	19 (30%)	6 (21%)
PhD degree	1 (2%)			
Total	63 (100%)	28 (100%)	63 (100%)	28 (100%)

According to the respondents, 36 of the DM Treatment group respondents reported that their "second parents" (or 57 percent) held at least a 4-year bachelor's degree or higher with 19 of them holding a master's degree or higher. Fourteen of the MD Control group parents (or 50 percent) held a 4-year bachelor's degree or higher with a six of them holding a master's degree or higher.

For the AR groups, 18 of the 27 AR Treatment group "first parents" (or 67 percent) held at least a 4-year bachelor's degree or higher with eight of them holding a master's degree or higher. As shown in Table 16, 12 of the 19 AR Control group parents (or 63 percent) were reported to have held a 4 – year bachelor's degree or higher with seven of them holding a master's degree or higher.

Table 16

Frequency Distribution: Parent Degree - AR

Degree	First Parent Degree		Second Parent Degree	
	AR Treatment Group	AR Control Group	AR Treatment Group	AR Control Group
Unknown			3 (11%)	
High school diploma or less	5 (19%)	4 (21%)	6 (22%)	4 (21%)
2-year diploma	4 (15%)	3 (16%)	7 (26%)	1 (5%)
4-year Bachelor's degree	10 (37%)	7 (37%)	5 (19%)	7 (37%)
Master's degree	7 (26%)	5 (26%)	6 (22%)	7 (37%)
PhD degree	1 (4%)			
Total	27 (100%)	19 (100%)	27 (100%)	19 (100%)

Eleven of the AR Treatment group second parents (41 percent) held at least 4-year bachelor's degree or higher with at least half of them with a master's degree or higher. While, 14 of the AR Control group parents (or 74 percent) held a 4-year bachelor's degree or higher with seven of them reported to hold a master's degree or higher.

Parents' career. The two questions related to the participants' parents' jobs were open-ended questions where participants listed their first and second parents' job. The list was categorized into STEM-related fields and Non-STEM related fields. The job categorization was based on O*NET Online (2014) categorizations of STEM Careers. Based on the participants' responses, approximately one-third of the "first parents" of the DM Treatment and one third of the DM Control groups had STEM-related careers. On the other hand, approximately, 40 percent of second parents of both the DM Treatment group and of the DM Control group held jobs within STEM-related careers.

Approximately, 45 percent of the first parents of the AR Treatment group had STEM-related careers, while 20 percent of first parents of the AR Control group had STEM-related careers. On the other hand, approximately, 50 percent of second parents of the AR Treatment group had STEM-related careers, while 40 percent of second parents of the AR Control group had STEM-related careers. Therefore, when comparing the parents' careers of the participants between the treatment and the control groups, it was recognized that the percentage of parents who had STEM-related fields were closely matched.

Parents' help in homework. Participants responded to a question concerning whether their parents helped them in completing their homework. The question provided three answer choices: no, sometimes, yes. Most participants in all four groups indicated that their parents always help them do their homework (yes) or sometimes help them do their homework (Sometimes). A small percentage of the participants, five (8 percent) from the DM Treatment, and one (4 percent) from the DM Control, and one (4 percent) from the AR Treatment groups, indicated that their parents do not help them at all (or responded No). Table 17 summarizes the actual participants' responses.

Table 17

Frequency Distribution: Parents' Help in Homework for Participants

Help	Group Name			
	DM Treatment	DM Control	AR Treatment	AR Control
No	5 (8%)	1 (4%)	1 (4%)	0 (0%)
Sometimes	21 (33%)	6 (21%)	7 (26%)	5 (26%)
Yes	37 (59%)	21 (75%)	19 (70%)	14 (74%)
Total	63 (100%)	28 (100%)	27 (100%)	19 (100%)

Usual science and math grades. Participants responded to a question asking them to indicate the letter grade that they usually receive in their science and math classes. Approximately, half of the participants in all groups selected an "A" as the letter grade they usually received in science classes except the AR Control in which three quarters of them selected an "A". While a little less than a half of all participants selected a "B" as the letter grade they usually received in science classes. Only three participants from the DM treatment group and three participants from the AR Treatment group selected a “C” as the letter grade that they usually received in science classes. Only one student from AR Treatment selected a “D” as his/her typical letter grade received in science. The student’s responses to the *Usual Science Grades* question are summarized in Table 18.

Table 18

Frequency Distribution: *Usual Science Grade*

Letter Grade	Group Name			
	DM Treatment Group	DM Control Group	AR Treatment Group	AR Control Group
A	31 (49%)	14 (50%)	13 (48%)	14 (74%)
B	29 (46%)	14 (50%)	10 (37%)	5 (26%)
C	3 (5%)	0 (0%)	3(11%)	0 (0%)
D	0 (0%)	0 (0%)	1 (4%)	0 (0%)
Total	63 (100%)	28 (100%)	27 (100%)	19 (100%)

For the *Usual Math Grade*, 67 percent (42/63) of the DM Treatment and 61 percent (17/28) of the DM Control groups’ participants listed an “A” as the letter grade that they usually receive in math. Twenty percent (13/63) of the DM Treatment and 32 percent (9/28) of the DM Control groups’ participants selected a “B” as the letter grade they usually receive in math. Thirteen percent (8/63) of the DM Treatment and 7 percent (2/28) of the DM Control groups’ participants chose “C” as the letter grade they usually received in math. The participants’ responses are displayed in Table 19.

Table 19

Frequency Distribution: *Usual Math Grade*- DM

Letter Grade	Group Name	
	DM Treatment	DM Control
A	42 (67%)	17 (61%)
B	13 (21%)	9 (32%)
C	8 (13%)	2 (7%)
Total	63 (100%)	28 (100%)

Seventy percent (19/27) of the AR Treatment and 74 percent (14/19) of the AR Control groups' participants chose an "A" as the letter grade they usually receive in math classes. Twenty-two percent (6/27) of the AR Treatment and 26 percent (5/19) of the AR Control groups' participants chose a "B" as the letter grade they usually receive in math classes. Only one student selected a "C" and one student selected "D" from AR Treatment group as the usual letter grade that he/she usually receives in math. The participants' responses are summarized in Table 20.

Table 20

Frequency Distribution: "*Usual Math Grade*"- AR

Letter Grade	Group Name	
	AR Treatment	AR Control
A	19 (70%)	14 (74%)
B	6 (22%)	5 (26%)
C	1 (4%)	
D	1 (4%)	
Total	27 (100%)	19 (100%)

It is clear from the results provided by these two questions that participants expect high grades in their science and math classes since "A" was the most common letter grade chosen as their expected grade, and "B" was the second most common letter grade. Very few participants selected a "C" or "D" as their expected math or science grade.

Participants' future career. The question related to the participants' future career interest was an open-ended question where participants listed their future career interest. The list was categorized into STEM-related fields and Non-STEM related fields. The job categorization was based on O*NET Online (2014). Based on the participants' responses, approximately a third of the DM Treatment and a third of the DM Control groups listed a STEM-related fields as their future career interest. Moreover, approximately, 40 percent of AR Treatment group and 45 percent of the AR Control group listed STEM-related fields as their future career interest. It seems that the interest in STEM-related careers is increasing between the beginning of the 6^{th} grade and the middle of the seventh grade in this school.

Critical Thinking Test Results

This section provides a description of the California Critical Thinking Skills Test (CCTST) scores for all groups including the time it took each student to complete his/her test and the completion percentage. Central tendency, normality, and variability for the CCTSTS overall and the six sub scores are discussed as well. Correlations of the CCTST with demographic variables such as the *Usual Science Grades* and the *Usual Math Grades*, and Michigan Educational Assessment Program (MEAP) scores are presented.

Approximately, 95 percent of all four participating groups completed 100 percent (all 25 questions) of the CCTST. The average number of minutes needed for the participants to complete the test varied according to their group and whether it was a pretest or a posttest. As one can see from Table 21, participants in all four groups took less time to complete their posttest than it took them to complete their pretest except the AR Control group. The DM Treatment group participants needed on average approximately the same time to complete their posttest as the average time needed to complete their pretest with only half a minute less. The

DM control group participants needed on average of four minutes less to complete their posttest as compared to their pretest. The AR Treatment group required an average of five minutes less to complete their posttest as compared to their pretest. The AR Control group participants required an average of one minute more to complete their posttest as compared to their pretest. It is not clear why there was an inconsistency in the number of minutes for AR groups, but it is possible that there was a class interruption during the AR groups' test administration or some other reason for the longer average posttest completion times.

Table 21

Time Needed to Complete the CCTST Test: Mean & Standard Deviation

Measure	Group Name							
	DM Treatment Group		DM Control Group		AR Treatment Group		AR Control Group	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
N	63	63	28	28	27	27	19	19
Mean minutes to complete test	23.06	22.49	22.39	18.32	25.52	20.26	23.42	24.47
Std. Deviation	5.297	4.895	5.322	3.432	9.12	3.789	5.167	5.358

Before discussing the actual results of the CCTST overall and subscale scores, one needs to recall the fact that the minimum possible score for the CCTST overall or any of its six subscale scores is 60 and the maximum possible score is 100 (Insight Assessment, 2015). In other words, the scores run over a 40-point span and not over a 100-point span. After calculating the mean scores of each group, the mean score differences between pre- and posttest were calculated.

As shown in Table 22, the difference of the average overall CCTST pre- and post- scores for the DM Treatment group was 2.08 raw score points. All six subscale scores demonstrated variable gains with the highest gain score for the Induction subscale, while the next highest was the Analysis. The lowest gain score was the Deduction subscale while the next lowest was for

Numeracy. The subscale scores for control group exhibited gains; however, these gains were not as high as those in the treatment group. As for the AR groups, the difference of average Overall CCTST pre- and post- scores for the AR Treatment group was 0.44 raw score points. The highest gain score for the six subscales score was for the Evaluation, while the next highest was Analysis. The lowest gain score was the Deduction subscale while the next lowest was for Numeracy, while the gain scores for Induction, Inference, and Numeracy subscales were negative. The AR control group had similar fluctuation in improvement scores as the AR Treatment.

Table 22

The CCTST Scores: Mean Differences-Pre/Post Tests - DM

Score Type	DM Treatment	DM Control
Overall	2.08	1.25
Analysis	2.56	1.71
Inference	2.27	1.18
Evaluation	1.57	1.29
Induction	2.79	-1.14
Deduction	1.30	1.68
Numeracy	1.40	0.57

The average overall DM CCTST pre- and post- gain score differences between males and females for the DM Treatment group were very close to each other (i.e., 0.05 points). While the average overall CCTST pre- and post- gain score differences between males and females for the AR Treatment group were approximately one point apart with males scoring lower than females [i.e., 1.006 points].

Hypothesis Testing

The main purpose of this section is to report the results of the testing of each of the four hypotheses listed in Chapter 1. The testing of the first two hypotheses utilized the paired samples t-test. The test is "a statistical method that is appropriate for comparing differences between two related groups" (Bernice, 2011, 6). This test is usually used when there are repeated measures on the same subject over a period of time (Zimmerman, 1997). "The paired t-test examines if the mean of the differences (effect of treatment) is discernable from zero (no effect)." (Park, 2009, 4). The paired samples t-test was selected because it looks at the pretest and posttest scores of each participant and determines if there was a significant difference between the participants' scores before and after treatments.

The last two hypotheses, however, were tested using an independent sample t-test. This test is usually used to compare results between two different groups that are not correlated (Zimmerman, 1997). The independent sample t-test compares the means of two samples taken from different population (Park, 2009). The third and the fourth hypotheses sought to test if there was a significant difference between the two different populations of male and female participants on the CCTST performance within each treatment groups. Therefore, it was appropriate to use the independent sample t-test for these hypotheses.

The testing of each hypothesis was based on a *P-value* of 0.05. When the difference between the tested variables was significant with a *P-value* of 0.05 or less, the null hypothesis was rejected; otherwise, the analysis of the data indicated a failure to reject the null hypothesis. The following sections present the hypotheses, the testing, and the results of analyses:

Null hypothesis One. The null hypothesis one states that "there is no significant difference between the CCTST scores of participants who have completed a GTT unit in Design & Modeling when compared to the scores of participants who have not completed such a GTT unit."

The analyses was conducted on the CCTST results to compare the pretest and posttest scores of DM Treatment and DM Control groups using normality measures and the paired samples t-test. The analyses were completed on the overall results and the subscales of analysis, deduction, evaluation, induction, inference, and numeracy. Table 23 shows the mean and the mean differences of the CCTST scores for each category between pre- and post- tests of the DM groups. In general, the DM participants' average performance on the CCTST scores improved on the posttest when compared to the pretest.

Table 23

The CCTST Scores-Mean & Mean Differences (Post-Pre) - DM

Score Type	Group Name			
	DM Treatment		DM Control	
	Mean	Difference	Mean	Difference
Overall Pre	75.63	2.08	76.29	1.25
Overall Post	77.71		77.54	
Analysis Pre	72.94	2.56	73.93	1.71
Analysis Post	75.49		75.64	
Inference Pre	78.03	2.27	78.29	1.18
Inference Post	80.30		79.46	
Evaluation Pre	75.73	1.57	76.54	1.29
Evaluation Post	77.30		77.82	
Induction Pre	79.37	2.79	81.29	-1.14
Induction Post	82.16		80.14	
Deduction Pre	72.87	1.30	72.25	1.68
Deduction Post	74.17		73.93	
Numeracy Pre	72.79	1.40	73.14	0.57
Numeracy Post	74.19		73.71	

Deduction was the only sub score in the DM Treatment group that improved slightly less than the DM Control group.

The paired samples t-test was performed to test the difference between the CCTST pretest and posttest scores for the DM Treatment and the Control groups. The results indicated that there were significant difference, at a *p-value* of *0.05* or less, between pretest and posttest scores of the DM Treatment group in all subscales but numeracy whose *p-value* was more than 0.05 [i.e., 0.076 points] as shown in Table 24. The *t values* were above |2| with 62 degrees of freedom (df) for all categories. On the other hand, there were no significant differences between pretest and posttest of the CCTST scores of the DM Control group. Therefore, the first null hypothesis was rejected for the DM treatment group.

Table 24

The CCTST Scores-Paired Samples T-Test - DM

Score Type	DM Treatment df = 62		DM Control df = 27	
	t	Sig. (2-Tailed)	t	Sig. (2-Tailed)
Overall Pre - Overall Post	-3.21	.002	-1.32	.199
Analysis Pre - Analysis Post	-3.86	.000	-1.64	.113
Inference Pre - Inference Post	-2.23	.029	-0.73	.470
Evaluation Pre - Evaluation Post	-2.14	.036	-1.16	.256
Induction Pre - Induction Post	-2.87	.006	0.95	.348
Deduction Pre - Deduction Post	-2.38	.020	-1.75	.092
Numeracy Pre - Numeracy Post	-1.81	.076	-0.47	.645

Null hypothesis two. The null hypothesis two states that "There is no significant difference between the CCTST scores of participants who have completed a GTT unit in Automation and Robotics when compared to the scores of participants who have not completed such a GTT unit."

The analyses were conducted on the CCTST results to compare the pretest and posttest scores of AR Treatment and AR Control groups using normality measures and the paired samples t-test. The analyses were completed on overall results and its subscales of analysis, deduction, evaluation, induction, inference, and numeracy. Table 25 shows the mean and the mean differences of the CCTST scores between pre- and post- tests of the AR groups. In general, AR participants' average performance on the pretest and the posttest CCTST scores were not consistent in terms of improvement. The inconsistency in the test results and in the average time it took the participants to complete their test (presented in the previous section) raises concerns about the AR groups' testing. In other words, there might have been some test administration or environmental circumstances during the test administration which may have impacted the AR participants' results on either the pre or posttest or both.

Table 25

The CCTST Scores-Means & Means' Differences (Post-Pre) - AR

Score Type	Group Name			
	AR Treatment		AR Control	
	Mean	Difference	Mean	Difference
Overall Pre	76.56	0.44	80.37	0.31
Overall Post	77		80.68	
Analysis Pre	74.07	0.41	77.26	1.69
Analysis Post	74.48		78.95	
Inference Pre	78.89	-0.74	83.16	0.89
Inference Post	78.15		84.05	
Evaluation Pre	76.63	1.52	80.84	-2.05
Evaluation Post	78.15		78.79	
Induction Pre	80.44	-1.03	83.58	2.31
Induction Post	79.41		85.89	
Deduction Pre	74.11	0.19	77.21	-1
Deduction Post	74.3		76.21	
Numeracy Pre	74.07	-0.51	75.74	1.21
Numeracy Post	73.56		76.95	

A paired samples t-test was performed to test the difference between the CCTST pretest and posttest scores for the AR Treatment and the Control groups. As shown in Table 26, the results indicated that there were no significant differences between pretest and posttest scores of the AR Treatment group in all subscales because their *p-values* were more than 0.05 in all categories. Similarly, there was no significant difference between the pretest and posttest scores for the CCTST overall scores and sub scores of the AR Control group as shown in Table 26. Based on the analysis results, this research failed to reject the second null hypothesis.

Table 26

The Paired Samples T-Test for the CCTST - AR

Score Type	AR Treatment df =26		AR Control df=19	
	t	Sig. (2-Tailed)	t	Sig. (2-Tailed)
Overall Pre - Overall Post	-.387	.702	-0.33	.742
Analysis Pre - Analysis Post	-0.32	.751	-1.17	.259
Inference Pre - Inference Post	0.47	.640	-0.99	.337
Evaluation Pre - Evaluation Post	-1.07	.293	1.91	.072
Induction Pre - Induction Post	0.52	.610	-1.45	.165
Deduction Pre - Deduction Post	-0.14	.892	0.76	.457
Numeracy Pre - Numeracy Post	0.30	.768	-0.64	.532

Since the overall improvement score was inconsistent for both of the AR groups, and there were drops in some of the CCTST subscale scores, concerns were raised regarding these inconsistencies that caused the researcher to question the procedures used for data collection. According to Insight Assessment (2015):

> Scores that drop precipitously at posttest require explanation. Critical-thinking skills do not deteriorate over short periods of time, unless there is an intervening cognitive injury, so the observation of significant drop in Overall Score from pretest to posttest for a given individual is an indicator of a false test a posttest. One can examine difference scores from pretest to posttest (posttest score – pretest score=difference score) and conservatively set a value as worthy of further examination and possibly indicative of a likely false posttest score. (p. 50)

The inconsistencies in the AR groups scores' may have been caused by a smaller group of participants who failed to provide a serious effort. In order to address this possibility, the individual scores of the participants of the AR groups were examined. Upon examination of the individual scores, it was discovered that several students scored much lower on the post-test than the pre-test. In an effort to establish the threshold for a "much lower" score, the overall CCTST confidence intervals were calculated for the AR Treatment group. As shown in Table 27, the interval was between (-1.92), and (2.81) while the AR Control confidence interval was between (-1.67) and (2.30).

Table 27

The Paired Samples T-Test for the CCTST - AR

Pair	Group Name	Paired Differences				t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Lower	Upper			
Overall Pre - Overall Post	AR Treatment	-.444	5.970	-2.806	1.917	-.39	26	.702
	AR Control	-.316	4.124	-2.303	1.672	-.33	18	.742

Therefore, the individual overall scores that fall below the confidence intervals which were approximately a three-point drop or more, were eliminated at this stage. The number of the AR Treatment group became 20 participants and the number of the AR Control group became 13 participants. Then the paired samples t-test for each AR group was recalculated. The results of the new paired samples t-test of the AR groups shown in Table 28 indicate there was a significant improvement in the overall scores of the CCTST for both of the AR treatment and the AR Control groups. However, there were differences in significance between the subscale scores for each group. The AR Treatment group had significant gains in the subscales of Evaluation, Deduction, and very close to a significant gain for the Analysis subscale score. There was no significant gain for the rest of the subscale scores (Inference, Induction, & Numeracy). The AR Control group had significant gain scores in the subscales of Analysis, Inference, Induction, and Numeracy, but no significant gain scores in Evaluation and Deduction.

Table 28

The Paired Samples Test for the CCTST Scores – AR (New)

Score Type	AR Treatment df = 19		AR Control df = 12	
	t	Sig. (2-Tailed)	t	Sig. (2-Tailed)
Overall Pre - Overall Post	-2.93	.009	-2.89	.014
Analysis Pre - Analysis Post	-2.07	.052	-3.36	.006
Inference Pre - Inference Post	-1.48	.155	-2.19	.049
Evaluation Pre - Evaluation Post	-2.56	.019	-0.15	.882
Induction Pre - Induction Post	-0.75	.464	-3.42	.005
Deduction Pre - Deduction Post	-2.25	.037	-1.07	.306
Numeracy Pre - Numeracy Post	-1.33	.200	-2.82	.016

The participants who were considered in calculating the new analysis of AR groups had similar demographics to the participants who were considered during the first analysis except for the *Usual Science Grade*. Eleven (84 percent) out of 13 participants of the AR Control group self-selected "A" as their *Usual Science Grade* while only 10 (50 percent) out of 20 of the AR Treatment group selected this grade.

When all AR treatment and control participants were considered, based on the overall CCTST there was a failure to reject the null hypothesis. However, when the outliers as defined by the threshold established by the confidence intervals established at the .05 level, the null hypothesis was rejected. Regarding the subscales of the CCTST scores without the outlines, there were differences between the six dimensions.

Null hypothesis Three. The third hypothesis states that "There is no significant difference between the CCTST scores of female participants who have completed a GTT unit in Design & Modeling when compared to male participants who completed the same unit in the same classes."

Normality tests and independent samples t-test were performed on the CCTST, overall and sub scores, of the DM Treatment group to check if there were differences in these scores between males and females. The differences in means are displayed in Table 29 which contain three main sections: the mean of pre- and post- test scores for males and females, the difference between pre- and post- test scores on each category for both males and females, and the difference between female and male scores for each separate pre- and posttest score.

Table 29

The CCTST Mean Differences: Sex - DM Treatment

CCTST Score	Mean		Differences (Post – Pre)		Differences (Females – Males)
	Male	Female	Male	Female	
Overall Pre	75.82	75.49	2.107	2.057	-0.336
Overall Post	77.93	77.54			-0.386
Analysis Pre	73.25	72.69	1.643	3.286	-0.564
Analysis Post	74.89	75.97			1.079
Inference Pre	77.64	78.34	3.321	1.429	0.700
Inference Post	80.96	79.77			-1.193
Evaluation Pre	76.29	75.29	1.571	1.571	-1.000
Evaluation Post	77.86	76.86			-1.000
Induction Pre	80.43	78.51	1.143	4.114	-1.914
Induction Post	81.57	82.63			1.057
Deduction Pre	72.50	73.17	1.821	0.886	0.671
Deduction Post	74.32	74.06			-0.264
Numeracy Pre	73.00	72.63	0.357	2.229	-0.371
Numeracy Post	73.36	74.86			1.500

The means of the pretests scores of males and females were not significantly different on all CCTST (overall and sub-scale) scores before starting the DM unit. Although the males scored slightly higher on the overall CCTST, the results were mixed for the sub-scale scores.

The independent sample t-test was performed on the CCTSTS of the DM Treatment group based on sex to test the difference between the scores of males and females. The results of the test indicated that there were no significant differences between them as shown in Table 30. Moreover, there were no significant differences in the variances of the CCTST scores between males and females except on the Deduction Post score with significance at a *p-value* of 0.035. A finding of significance in only one of the six sub scale scores is not enough to reject the null hypothesis, therefore, an analysis of the results failed to reject the null hypothesis.

Table 30

The CCTST Independent Samples Test: Sex - DM Treatment

Score	t-test for Equality of Means		
	t	df	Sig. (2-tailed)
Overall Pre	.251	61	.803
Overall Post	.305	61	.762
Analysis Pre	.428	61	.670
Analysis Post	-.876	61	.384
Inference Pre	-.358	61	.722
Inference Post	.707	61	.482
Evaluation Pre	.717	61	.476
Evaluation Post	.706	61	.483
Induction Pre	1.208	61	.232
Induction Post	-.543	61	.589
Deduction Pre	-.513	61	.610
Deduction Post	.225	61	.823
Numeracy Pre	.248	61	.805
Numeracy Post	-1.023	61	.310

Null hypothesis four. The fourth null hypothesis states "There is no significant difference between the CCTST scores of female participants who have completed a GTT unit in Automation and Robotics when compared to male participants who completed the same unit in the same classes."

Normality tests and Independent sample t-test were performed on all scores of the CCTST of the AR Treatment group to check if there were differences in these scores between males and females. The results of mean differences are displayed in Table 31 which contain three main sections: the mean scores of pre- and post- test scores of males and females, the difference between post- and pre- test on each category for both males and females, and the difference between females and males for each score, pre and post separately.

Table 31

The CCTST Means & Means' Differences: Sex – AR Treatment

CCTST Score	Mean		Post - Pre		Females - Males
	Male	Female	Male	Female	
Overall Pre	77.92	75.29	-0.077	0.929	-2.637
Overall Post	77.85	76.21			-1.632
Analysis Pre	75.54	72.71	0.154	0.643	-2.824
Analysis Post	75.69	73.36			-2.335
Inference Pre	80.08	77.79	-0.846	-0.643	-2.291
Inference Post	79.23	77.14			-2.088
Evaluation Pre	78.31	75.07	-0.154	3.071	-3.236
Evaluation Post	78.15	78.14			-0.011
Induction Pre	81.85	79.14	-0.923	-1.143	-2.703
Induction Post	80.92	78.00			-2.923
Deduction Pre	75.15	73.14	-0.154	0.500	-2.011
Deduction Post	75.00	73.64			-1.357
Numeracy Pre	75.46	72.79	-0.231	-0.786	-2.676
Numeracy Post	75.23	72.00			-3.23

There was a mixed pattern when examining the improvement scores (between pre- and post- testing) for both males and females. There appear to be no discernable patterns to these results. There may have been test administration and/or environmental variables which may have impacted the results.

The independent sample t-test was performed on the CCTSTS of the AR Treatment group based on sex to test the difference between the scores of males and females. The results of the test indicated that there were no significant difference in the CCTST mean scores between female and male participants as shown in Table 32 Moreover, there were no significant differences in the CCTST variance scores between males and females. Therefore, the analysis of the data failed to reject the null hypothesis.

Table 32

The CCTST Independent Samples Test: Sex - AR Treatment

	t-test for Equality of Means		
	t	df	Sig. (2-tailed)
Overall Pre	.917	25	.368
Overall Post	.603	25	.552
Analysis Pre	1.047	25	.305
Analysis Post	.812	25	.425
Inference Pre	.651	25	.521
Inference Post	.682	25	.501
Evaluation Pre	1.057	25	.301
Evaluation Post	.004	25	.997
Induction Pre	0.655	25	.519
Induction Post	.959	25	.347
Deduction Pre	.677	25	.505
Deduction Post	.487	25	.630
Numeracy Pre	.917	25	.368
Numeracy Post	0.991	25	.331

Null hypothesis five. The fifth null hypothesis states "There is no significant correlation between each of the demographic variables (i.e., sex, socioeconomic status, students future career interest, parents education and jobs, parents help to student in homework, the *Usual*

Science Grade, the *Usual Math Grade,* MEAP [science, math, & reading]) and the CCTST scores."

Analyses were conducted on all four combined group results to determine if there was a correlation between the CCTST overall scores and each of the demographic variables. The results of the analysis indicated that there is a significant correlation, at a *p-value* less than *0.05*, between the overall CCTST scores and each of the academic performance measures which were: the *Usual Science Grade*, the *Usual Math Grade*, the MEAP Science total score, the MEAP Math total score, and the MEAP reading total score. Table 33 summarizes these positive correlations. All variables were significant at the .001 level except the MEAP reading Score which while still significant was only significant at the .05 level.

Table 33

The CCTST Overall Scores & Academic Performance: Correlation Table

Demographic Variable	Overall Post	
	Pearson Correlation	Sig. (2-tailed)
Usual Science Grade Post (N=137)	.465	.000
Usual Math Grade Post (N=137)	.364	.000
MEAP Science Score (N=70)	.568	.000
MEAP Math Score (N=98)	.411	.000
MEAP Reading Score (N=97)	.239	.019

The results of the correlation analysis between the overall CCTST posttest scores and the demographic variables related to parents (i.e., education, jobs, and their help to their student) showed no significant correlation. The *second parents' degrees* and *second parent jobs* variables were close to significance sine the P values were between .05 and .1. Table 34 shows the correlation table.

Table 34

The CCTST Overall Scores & Parents Demo: Correlation Table (N=137)

Demographic Variable	Overall Post	
	Pearson Correlation	Sig. (2-tailed)
Parent 1 Degree	.047	.586
Parent1 Job	-.009	.918
Parent 2 Degree	.144	.094
Parent2 Job	.149	.083
Parents' Help in HW Post	-.084	.331

The results of the correlation analysis between the overall CCTST posttest scores and the demographic variables relate to student (i.e., sex, socioeconomic status, and the *student's future interest career*) showed no significant correlation except for socioeconomic status. The socioeconomic status of the sample had a significant negative correlation with the overall CCTST posttest score. The *Student's Future Career Interest* of STEM careers was very close to being significantly correlated with the overall CCTST posttest score sine the P values were between .05 and .1. Table 35 shows the correlation table for these demographic variables.

Table 35

The CCTST Overall Scores & Students Demo: Correlation Table (N=137)

Demographic Variable	Overall Post	
	Pearson Correlation	Sig. (2-tailed)
Sex	-.016	.851
Socio Economic Status	-.303	.000
Student's Future Career Interest	.143	.096

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Summary

The research attempted to determine the impact of PLTW GTT Foundation units on participants' critical-thinking skills. The results of the demographic questions and the CCTST were summarized in this chapter. The demographic data provided a full description of the participants' background including sex, ethnicity, age, socioeconomic status, and parents' education. Additionally, it provided the academic background of the participants including their Usual Science and Math grades, and MEAP scores.

The participants' male to female ratios were close to fifty percent across all four groups. The majority of participants were white/Caucasian with very little diversity. The ages of the participants were within the normal range of middle school students which was between 11and 14 years old. Approximately, 20 percent of participants, across all four groups, were economically disadvantaged with either free or reduced lunch status. The participants' parents had a variety of degrees ranging from high school diploma to PhD degrees. The participants were, in general, from above average academic performance levels as indicated by the *Usual Science Grades* and the *Usual Math Grades*, and MEAP results with most participants' performances being around a little above average ranges.

Pretest and Posttest scores of the CCTST were compared between treatment and control groups. The DM Treatment group posttest scores were significantly higher than those of the control group on both the overall CCTST and subscales scores with the one exception of the numeracy sub-scale. On the other hand, the AR Treatment group scores were not significantly different from the control group scores.

When comparing the CCTST scores between female and male participants who completed DM or AR unit, no significant difference in the improvement scores between females and males was found which means that the treatment (i.e., DM or AR unit) was similarly effective in helping female and male participants improve their critical-thinking skills. Table 33 summarizes the hypotheses testing in this study.

When investigating if there was a correlation between the overall CCTST posttest scores and each of the demographic variables, it was found that there was a significant positive correlation (at *p-value* of .05) between the overall CCTST posttest scores and each of the academic achievement indicators (*Usual Science Grade, Usual Math Grade, MEAP[Math, Science, and, Reading]).* Additionally, a negative correlation with the socioeconomic status. While there was no significant correlation between the overall CCTST posttest scores and each of the rest of the demographic variables.

Table 36

Null Hypotheses Testing Summary

Null Hypo.	Group	Testing	Result
H_0 1	DM Treatment & DM Control	DM Treatment impact	Rejected
H_0 2	AR Treatment & AR Control	AR Treatment impact	Failed to reject (original participants) Rejected (excluding some participants)
H_0 3	DM Treatment	Female vs. Male	Failed to reject
H_0 4	AR Treatment	Female vs. Male	Failed to reject
H_0 5	All Groups	Demographic variables	Rejected for *Usual Science Grade, Usual Math Grade, MEAP[Math, Science, and, Reading], & socioeconomic status.* Failed to reject for sex, parents education, parents degree, parents help in homework to student, student's future STEM career interest.

Chapter 5: Summary, Conclusions, and Recommendations

This research examined the impact of the two Project Lead The Way (PLTW)-Gateway to Technology (GTT) Foundation units on middle school students' critical-thinking skills. A quasi-experimental research approach was used in this study by administering a critical-thinking skills test along with a set of demographic questions as both a pre and post-test instrument. This Chapter will provide a brief summary of the findings, identify the conclusions based on these findings and provide recommendations for practice and for future research.

Summary of Findings

This section covers the findings of this study including the results regarding the participant demographics, the California Critical Thinking Skills Test (CCTST) results, and the four hypotheses tests.

Findings regarding demographics. The sample consisted of students selected from a suburban middle school in Michigan while the population consisted of students from schools with similar characteristics from across the nation. The total number of participants whose results were used in the study were as follows: Design and Modeling (DM) Treatment, 63, DM Control, 28, Automation and Robotics (AR) Treatment, 27, and AR Control, 19. The age of the participants was normal for the grade levels. The females to males ratio in each group was very close to one to one, the majority of participants in each group were from white/Caucasian ethnic backgrounds, about a fifth of participants in each group were economically disadvantaged, the degrees held by the parents of the participants ranged from a high school diploma to PhD degrees, and the participants from each group demonstrated above average academic performance levels as measured by their mean MEAP scores. Self-reported interest in STEM careers with the DM groups (6th grade) was approximately 30 percent while the AR groups (7th grade) was around 40 percent.

Findings regarding the CCTST. The difference between the average overall CCTST pre- and post- scores for the DM Treatment group was 2.08 raw score points. The minimum and maximum scores for the CCTST was 40 and 100 respectively. All subscales scores demonstrated gains as well. The highest gain score for the six subscales was the score for Induction, while the next highest was Analysis. The lowest gain score was the Deduction subscale while the next lowest was for Numeracy. The subscale scores for the control group exhibited gains; however, these gains were not as high as those in the treatment group nor were they significant.

The difference of average overall CCTST pre- and post- scores for the AR Treatment group was 0.44 raw score points. The highest gain score for the six subscales score was for Evaluation, while the next highest was Analysis. The gain scores for the Induction, Inference, and Numeracy subscales were negative.

The average overall DM CCTST pre- and post- gain score differences between males and females for the DM Treatment group were very close to each other (i.e., 0.05 points). While the average overall CCTST pre- and post- gain score differences between males and females for the AR Treatment group were approximately one point apart with males scoring less than females (i.e., 1.006 points).

Findings regarding the hypothesis testing. There were four tested hypotheses. The first two hypotheses were tested by using the paired samples t-test. The third and fourth hypotheses were tested using the independent samples t-test. Additionally, the differences between mean scores of each group were calculated as well. The following is the list of hypotheses and the results of testing each one of them:

Null hypothesis one. The null hypothesis one states that "there is no significant difference between the CCTST scores of participants who have completed a GTT unit in "Design & Modeling" when compared to the scores of participants who have not completed such a GTT unit."

The paired samples t-test indicated that there was a significant difference, at a *p-value* of *less than .05*, between pretest and posttest scores of the DM Treatment group on all subscales except numeracy whose *p-value* was more than 0.05 (i.e., 0.076). On the other hand, there were no significant differences between pretest and posttest of the CCTST scores of the DM Control group. Therefore, the first null hypothesis was rejected for the DM treatment group.

Null hypothesis two. The null hypothesis two states that "There is no significant difference between the CCTST scores of participants who have completed a GTT unit in "Automation and Robotics" when compared to the scores of participants who have not completed such a GTT unit."

The paired samples t-test results indicated that there were no significant differences between the pretest and posttest scores of the AR Treatment group in all subscales because their *p-values* were more than 0.05 for all subscale scores. Similarly, there were no significant differences between the pretest and posttest scores for the CCTST overall scores and the sub scores of the AR groups. Based on the analysis of all valid participants, this research failed to reject the second null hypothesis. Upon noting that some sub-scale scores actually dropped, the researcher undertook another series of analyses. Based on calculating a confidence interval, the results of participants who dropped more than 3 points on the posttest were excluded from the second set of analyses (AR Treatment=20, AR Control =13). These additional analyses revealed a significant impact of the AR treatment on participants' critical thinking scores. Based on this new analysis of the smaller group, Hypothesis 2 was conditionally rejected.

Null hypothesis three. The third hypothesis states that "There is no significant difference between the CCTST scores of female participants who have completed a GTT unit in Design & Modeling when compared to male participants who completed the same unit in the same classes."

An independent sample t-test was performed on the CCTSTS scores of the DM Treatment group based on sex indicated that there were no significant differences between the scores of males and females. Moreover, there were no significant differences in the variances of the CCTST scores between males and females except on the Deduction Post score with significance at a *p-value* of 0.035. A finding of significance in only one of the six sub scale scores is not enough to reject the null hypothesis; therefore, an analysis of the results failed to reject the null hypothesis.

Null hypothesis four. There is no significant difference between the CCTST scores of female students who have completed a GTT unit in Automation and Robotics when compared to male participants who completed the same unit in the same classes.

The independent sample t-test which was performed on the CCTSTS of the AR Treatment group based on sex indicated that there were no significant differences between the scores of males and females. Therefore, the analysis of the data failed to reject the fourth null hypothesis.

Null hypothesis five. There is no significant correlation between the demographic variables (i.e., *sex, socioeconomic status, students' future career interest, parents' education and* *jobs, parents' help to student in homework*, the *Usual Science Grade*, the *Usual Math Grade*, MEAP [science, math, & reading]) and the CCTST scores.

Correlation analyses were conducted to test if there was a correlation between the overall CCTST posttest scores and the demographic variables for all combined groups. There were significant positive correlations, at a *p-value* less than 0.05, between the CCTSTS scores and the following demographic variables: positive correlations with *Usual Science Grade*, the *Usual Math Grade*, and MEAP (science, math, & reading). A negative significant correlation was found between socioeconomic status and the overall CCTST score. Therefore, for the aforementioned variables the hypotheses was rejected. On the other hand, there was no significant correlation with the remaining demographic variables which resulted in a failure to reject the hypotheses for these variables.

Conclusions

The following are the conclusions based on the findings:

- The PLTW- Design and Modeling (DM) unit has an overall positive significant impact on the critical-thinking skills as measured by the CCTST of middle school students in settings similar to the sample setting. Related studies have suggested that project-based learning impacts students positively (Duran and Sendag, 2012; Lammi, 2011;Dindial, 1990). Since PLTW relies heavily on project-based learning, the results of this study are consistent with some earlier efforts.
- In schools with similar characteristics, the PLTW- DM unit can be expected to have a significant impact on each of the following CCTST subscale scores of middle school students: Analysis, Inference, Evaluation, Induction, and Deduction.

- The DM Treatment group did not have a significant improvement between pre- and posttest of the Numeracy subscale of the CCTST. In studies focusing on PLTW high school engineering programs, Kelley (2008) and Kelley, Brenner, Pieper (2010), concluded that PLTW engineering programs do not address mathematical concepts in any significant fashion. More specifically, the two studies raised concerns that the students enrolled in PLTW did not adequately apply mathematical computations, prediction, and optimization in problem solving. It is interesting to note that it is recommended that high schools require PLTW Engineering students to be enrolled in college-bound math classes while simultaneously enrolled in their PLTW class.
- Based on the analysis of all available data, the PLTW Automation and Robotics (AR) unit had no significant impact on the critical-thinking skills of middle school students in schools with similar characteristics to the sample school. When the scores of students who appeared to have not taken the post-test seriously were dropped based on the calculated confidence interval, then the new analysis yielded a significant difference.
- The PLTW foundation units (DM & AR) impact both males and females similarly.
- The overall California Critical Thinking Skills Test (CCTST) scores exhibited a significant positive correlation with other variables including: the individual MEAP total scores in Math, Science, and Reading along with the self-reported *Usual Math Grade* and the self-reported *Usual Science Grade* that students usually receive. This finding is consistent with previous studies that showed the reliability of the CCTST and its correlation with the academic performance (Bycio, Joyce, 2009; Terry & Ervin, 2012; Deal & Pittman, 2009, Daiek, 1993).

Recommendations

The following recommendations are based on the results of this study…

- Administrators of middle schools who desire to improve their students' critical-thinking skills in general and in the analysis, inference, evaluation, induction, and deduction, in particular, could benefit from implementing the PLTW Design and Modeling unit for all students.
- Those responsible for updating and improving PLTW-GTT curricula should attempt to better address the Numeracy construct embedded in the CCTST. This could possibly be addressed by adding projects that involve mathematical concepts such as in predicting results, computing, and estimation (Kelley, 2008; & Kelley, Brenner, & Pieper, 2010).
- The California Critical Thinking Skills Test (CCTST) appears to be a reasonable and reliable instrument that can be used to measure the impact of an intervention such as a GTT foundation unit on students' critical-thinking skills.
- Although the GTT AR unit did not result in improved scores on the CCTST test in this research, several concerns emerged regarding the data collection steps used in this study that justify further research focused on the AR unit using the CCTST.
- Administrators of middle schools who desire to improve their female as well as male students' critical-thinking skills in general could benefit from implementing the PLTW Design and Modeling and Automation and Robotics units.

Suggestions for Future Research

This study found a positive impact of the GTT DM unit on the CCTST in a setting with little diversity, a relatively high socioeconomic status, and relatively high student achievement. Future studies using the CCTST are suggested in a variety of settings such as middle schools with high levels of diversity, families with lower socioeconomic status, and schools with lower levels of academic achievement. Future studies in urban and rural schools as well as additional suburban schools are suggested in order to firm up conclusions about the effectiveness of PLTW middle school units on critical-thinking skills and academic performance.

It is recommended that a longitudinal study be conducted on middle school students starting at the beginning of the sixth grade and ending at the end of the eighth grade. Two groups of students, control and treatment, could constitute the sample for this study. The treatment will be exposing students to two units of the PLTW-GTT program every school year (grades 6 – 8). Students are tested before the start of sixth grade and tested again right after completing eighth grade.

Similar studies on each of the eight PLTW-GTT units could be conducted with similar conditions or using pairs of units where students would be exposed to two units per academic year instead of one and the control groups would not be exposed to any unit. In other words, comparing the impact of the exposure to multiple PLTW-GTT units on students as compared to students who took some or none and/or conduct similar research where the impact of the PLTW units is tested yearly.

Additionally there was evidence that students' interest in STEM careers increased from 30 percent to 40 percent between the beginning of grade six and the middle of grade seven. Therefore, it is recommended that future researchers investigate this phenomenon which appears to be inconsistent with prevailing beliefs about STEM interests. Finally, it is recommended that future studies investigate the relationship between CCTST scores with ethnicity and race.

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Appendices

Appendix A: Informed Assent PLTW Student

Informed Assent
PLTW Student

You are invited to participate in a research study that is a collaboration effort between your school district and Eastern Michigan University in order to determine the impact of the Project Lead The Way (PLTW) Gatway To Technology (GTT) units on students' critical thinking. Your participation is voluntary and you can withdraw from the study at any time.

You are going to be asked to complete a critical thinking test on two occasions that are approximately ten weeks apart. Each test will take about than 45 minutes for you to complete. The critical thinking test will measure critical-thinking skills and it consists of 25 multiple-choice questions. Additionally, you will be asked to complete a demographic questionnaire before taking the test which includes: Gender, ethnicity, free and reduced lunch status, your parents' education/occupation, academic courses taken, expected grades in math and science classes, and your future job/career interest.

Your answers will be treated confidentially and will not be seen by anyone at your school.

Future Questions: If you have any questions concerning your participation in this study now or in the future, you may contact the principal investigator, Rula Hashem via e-mail (rhashem@emich.edu).
Agreement to Participate: I have read all the above information about this research study. All my questions, at this time, have been answered and I agree to voluntarily take part in the study.

PRINT NAME:

Signatures:

Participant (your signature) Date:

Investigator or Specified Designee Date:

Appendix B: Informed Assent Non-PLTW Student

Informed Assent

You are invited to participate in a research study that is a collaboration effort between your school districts and Eastern Michigan University in order to determine the factors that could affect middle students' critical-thinking skills. Your participation is voluntary and you can withdraw from the study at any time.

You are going to be asked to complete a critical thinking test on two occasions that are approximately ten weeks apart. Each test will take about than 45 minutes for you to complete. The critical thinking test will measure critical-thinking skills and it consists of 25 multiple-choice questions. Additionally, you will be asked to complete a demographic questionnaire before taking the test which includes: Gender, ethnicity, free and reduced lunch status, your parents' education/occupation, academic courses taken, expected grades in math and science classes, and your future job/career interest.

Your answers will be treated confidentially and will not be seen by anyone at your school.

Future Questions: If you have any questions concerning your participation in this study now or in the future, you can contact the principal investigator, Rula Hashem via e-mail (rhashem@emich.edu)
Consent to Participate: I have read all the above information about this research study. All my questions, at this time, have been answered and I agree to voluntarily take part in the study.

PRINT NAME:

Signatures:

Participant (your signature) Date:

Investigator or Specified Designee Date:

Appendix C: Informed Consent PLTW Parent

Informed Consent
PLTW Parent

Project Title: Impact of PLTW on Critical-thinking skills.
Investigator: Rula Hashem, Research Fellow, Eastern Michigan University.
Co-Investigator: John C. Dugger, Ph.D., Professor, School of Technology Studies.
Purpose of the Study: The purpose of this **research** is to gain better understanding of the impact of Project Lead The Way (PLTW) Gateway to Technology (GTT) units on students' critical-thinking skills using a critical thinking test.
Procedure: A research assistant will explain the study to your child, and answer any questions he/she may have. Your child must be a middle school student to take part in this study. Upon completing the tests, your child will be given a duplicate copy of this informed consent, which includes follow-up contact information, if needed.
Your child will be asked to complete a critical thinking test one time before taking PLTW-GTT unit and another time the same test after completing PLTW-GTT unit/s which is approximately ten weeks apart. The total expected time needed to complete the test is be about 45 minutes. The test will measure critical-thinking skills and it consists of 25 multiple-choice questions. Your child will be asked to complete a demographic questionnaire before taking the test which includes: Gender, ethnicity, free and reduced lunch status, parents' education/occupation, academic courses taken, expected grades in math and science classes, and your child's future job/career interest.

Confidentiality: Only a code number will identify your child's tests' responses. The results will be stored separately from the consent form, which includes your name and any other identifying information. At no time will your name be associated with your responses to the tests.
All related materials will be kept in locked file cabinets in the researcher's office and electronic data will be stored on a password-protected computer.

Expected Risks: There are no foreseeable risks to you by completing this survey, as all results will be kept completely confidential.
Expected Benefits: There will be no direct personal benefit to you, but your participation will contribute to our understanding of how Project Lead The Way affect students' career choices and it will help us identify factors that could affect their career choices.

Voluntary Participation: Participation in this study is voluntary. You may choose not to participate. If you do decide to let your child participate, you can change your mind at any time and withdraw your child from the study without negative consequences.

Use of Research Results: Results will be presented in aggregate form only. No names or individually identifying information will be revealed. Results may be presented at research meetings and conferences, in scientific publications, and as part of a doctoral dissertation being conducted by the principal investigator.

Future Questions: : If you have any questions concerning your participation in this study now or in the future, you can contact the principal investigator, Rula Hashem, at via e-mail (rhashem@emich.edu)

This research protocol and informed consent document has been reviewed and approved by the Eastern Michigan University Human Subjects Review Committee for use from _____________ to _____________ (date). If you have questions about the approval process, please contact the Director of the Graduate School (734.487.0042, human.subjects@emich.edu).

Consent to Participate: I have read or had read to me all of the above information about this research study, including the research procedures, possible risks, side effects, and the likelihood of any benefit to me or to my child. The content and meaning of this information has been explained and I understand. All my questions, at this time, have been answered. I hereby consent and do voluntarily offer to allow my child to take part in the study.

PRINT NAME:

Signatures:

Participant (your signature) Date:

Investigator or Specified Designee Date:

Appendix D: Informed Consent Non-PLTW Parent

Informed Consent
Parent

Project Title: Impact of PLTW on Critical-thinking skills.
Investigator: Rula Hashem , Research Fellow, Eastern Michigan University.
Co-Investigator: John C. Dugger, Ph.D., Professor, School of Technology Studies.
Purpose of the Study: The purpose of this **research** is to gain a better understanding of the factors that could affect students' critical-thinking skills using a critical-thinking skills test.
Procedure: A research assistant will explain the study to your child, and answer any questions he/she may have. Your child must be a middle school student to take part in this study. Upon completing the tests, your child will be given a duplicate copy of this informed consent, which includes follow-up contact information, if needed.
Your child will be asked to complete a critical thinking test at the beginning of the study period and at the end of the study period which will be about ten weeks apart. The approximate total time needed to complete the test is be about 45 minutes. The test will measure critical-thinking skills and it consists of 25 multiple-choice questions. The test will measure critical-thinking skills and it consists of 25 multiple-choice questions. Your child will be asked to complete a demographic questionnaire before taking the test which includes: Gender, ethnicity, free and reduced lunch status, parents' education/occupation, academic courses taken, expected grades in math and science classes, and your child's future job/career interest.

Confidentiality: Only a code number will identify your child's tests' responses. The results will be stored separately from the consent form, which includes your name and any other identifying information. At no time will your name or your child's name be associated with the responses to the tests.
All related materials will be kept in locked file cabinets in the researcher's office and electronic data will be stored on a password-protected computer.

Expected Risks: There are no foreseeable risks to your child by completing this test, as all results will be kept completely confidential.

Expected Benefits: There will be no direct personal benefit to your child, but your participation will contribute to our understanding of what affects students' critical-thinking skills.

Voluntary Participation: Participation in this study is voluntary. You may choose not to let your child participate. If you do decide to let your child participate, you can change your mind at any time and withdraw your child from the study without negative consequences.

Use of Research Results: Results will be presented in aggregate form only. No names or individually identifying information will be revealed. Results may be presented at research meetings and conferences, in scientific publications, and as part of a doctoral dissertation being conducted by the principal investigator.

Future Questions: : If you have any questions concerning your participation in this study now or in the future, you can contact the principal investigator, Rula Hashem, via e-mail (rhashem@emich.edu)

This research protocol and informed consent document has been reviewed and approved by the Eastern Michigan University Human Subjects Review Committee for use from _____________ to _____________ (date). If you have questions about the approval process, please contact the Director of the Graduate School (734.487.0042, human.subjects@emich.edu).

Consent to Participate: I have read or had read to me all of the above information about this research study, including the research procedures, possible risks, side effects, and the likelihood of any benefit to me or my child. The content and meaning of this information has been explained and I understand. All my questions, at this time, have been answered. I hereby consent and do voluntarily offer to allow my child to take part in the study.

PRINT NAME:

Signatures:

Participant (your signature) Date:

Investigator or Specified Designee Date:

Appendix E: Demographics Questionnaire

Student Identification code ___________________________

Please respond to the following questions related to your demographic information to the best of your knowledge:

I) General Characteristics

1) Sex: ☐ Male ☐ Female

2) Ethnicity:

☐ Asian

☐ American Indian or Alaskan Native

☐ Black or African American

☐ Hispanic or Mexican origin

☐ Caucasian or White

☐ Middle Eastern

☐ Two or more races

3) Which of the following best describes you:

☐ I qualify for **free** lunch

☐ I qualify for **reduced** lunch

☐ I pay the full lunch price (I do not qualify for free or reduced lunch).

4) What is the highest level of education of your **mother or primary guardian**?☐ High school diploma or less

☐ 2-year diploma

☐ 4-year Bachelor's degree

☐ Master's degree

☐ PhD degree

5) List the job/work that the **mother/primary guardian** does for living?

____

6) What is the highest level of education of your **second parent if living with you**?☐ High school diploma or less

☐ Two year diploma

☐ Four year Bachelor degree

☐ Master's degree

☐ PhD degree

7) List the job/work that the **second parent** who is living with you does?

____

8) Do either of your parents help you study?

☐ Yes, most of the time ☐ Sometimes ☐ No

Background Information-Education

9) What grade do you usually get in **SCIENCE** courses in general (which grades have you typically received)?

☐ A ☐ B ☐ C ☐ D ☐ F

10) What grade do you usually get in MATH courses in general (which grades have you typically received)?

☐ A ☐ B ☐ C ☐ D ☐ F

11) What job or career you like to pursue after high school and/or college?

____

Appendix F: California Critical Thinking Test- Form M25 Description

CCTST M25

The CCTST M25 is calibrated to measure the critical thinking and quantitative reasoning of middle school children (grades 6-9)

Test Purpose

Critical thinking and quantitative reasoning in one assessment. Students possessing strength in critical thinking are better equipped to solve problems, to understand and to integrate content material, and to achieve in school. Success in middle school years requires students to understand and apply increasingly sophisticated concepts and information. Middle school instruction is important because core reasoning skills can be developed or can fail to blossom depending on the quality of the instruction. The more students are supported and challenged to exercise their core critical-thinking skills, the stronger these skills become.

The CCTST M25 is an objective measure of critical-thinking skills and quantitative reasoning at the middle school level. Comprehensive reports provide important individual and group diagnostics. Quick, easy to administer, the CCTST M25 delivers results that are locally relevant immediately. Given at the beginning and/or end of the school year, reports provide metrics that are used to:

Test Overview

Children, adolescents and adults alike need to be able to think critically about the mathematical and numerical information that surrounds them in the media, on the Internet, in schools and workplaces, and in society at large. Fostering the development of overall critical-thinking skills at this level pays off across the curriculum and in the future workplace. The CCTST M25 provides age-appropriate items that use comfortable, everyday, common sense topics and vocabulary to engage the test-taker in applying his or her critical-thinking skills. Every question is familiar, relevant and provides all necessary content to isolate thinking process. The CCTST M25 is timed for 45 minutes which permits maximum performance within the range of possible effort for the intended test-taker group.

Test Administration

The CCTST M25 can be administered online using Insight Assessment's secure, encrypted online e-testing interface or in paper and pencil mode. The M25 can be delivered through Blackboard, Moodle or many other learning management systems in use at your company or educational institution. Because these LMS products vary, and your company installation will differ, we work directly with your in-house technology representative during set-up to ensure a smooth solution

Scale Scores Reported

The CCTST M25 provides an *Overall Reasoning* score, and scores on five critical-thinking skills that are vital for educational success: *analysis*, *evaluation*, *inference*, *induction* and *deduction*. The M25 also provides a valuable additional scale: *Numeracy*.

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Source: http://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/CCTST-M25

Appendix G: Survey of Studies of PLTW Middle & High school Programs

Table

Survey of Studies of PLTW engineering programs – Middle & High school

#	Title Author (Year)	Author (Year)	Type	PLTW Program	Investigated topic
	Project Lead The Way: A pre-engineering curriculum that works-A new design for high school career/technical studies	Bottoms & Anthony (2005)	Report	HS	Math & science achievement College attendance Enrollment in cross circular courses
1	Curriculum consonance in technology education classrooms: The official, intended, implemented, and experienced curricula	Brown (2007)	Dissert.	HS - IED	Consistency in curriculum delivery Computer knowledge skills Future career preparation
2	Cognitive processes of students participating in engineering-focused design instruction.	Kelley (2008)	Research	HS – IED & POE	Cognitive processes of students participating in engineering problem. Problem-solving skills
3	Efficacy of Project Lead The Way" curricula in improving mathematics skills for students in the high schools of a small metropolitan school district –	Wheeler (2008)	Dissert.	HS – IED & POE	Mathematics achievement Mathematics achievement of minorities and females
4	Impact of water resources risk analysis on engineering education in rural counties -Thesis	Boynton (2009).	Report	HS – POE	Enrollment of STEM related fields Student performance in engineering, science, & math
5	Comparing high school students' and adults' perceptions of technological literacy-	Harrision (2009)	Dissert.	HS	Students 'perceptions of technology literacy
6	PLTW and Epics-High: Curriculum comparisons to support problem solving in the context of engineering design.	Kelley, Brenner, & Pieper (2010)	Report	HS	Comparison in problem-solving skills of two approaches to engineering curriculum
7	Facilitating engineering baccalaureate completion among Wisconsin technical college system transfer students	Sielaff (2010)	Dissert.	HS	Students perspective on factors impacting Engineering college persistence
8	Project Lead The Way-Initial Program evaluation.	Kingsbury (2010)	Report	HS	Student achievement Minority performance gaps Math and science enrollment
9	Evaluation of Project Lead The Way in Rockwell-sponsored middle schools –	Heywood & White (2011)	Report longitudinal study	MS - DM & AR HS – IED & POE	Math and science achievement Enrollment in advanced math & science courses
10	Integrating science and mathematics instruction in a middle school STEM course: The impact on attitudes, career aspirations and academic achievement in science and mathematics –	Kutch (2011)	Dissert.	MS	Students' achievement in math and science Interest in engineering careers Students' attitude towards science, math, and engineering

Table

Survey of Studies of PLTW engineering programs – Middle & High school

#	Title Author (Year)	Author (Year)	Type	PLTW Program	Investigated topic
11	Factors influencing the self-efficacy of Black high school students enroll led in PLTW pre-engineering courses –	Martin (2011)	Dissert.	HS	Self-efficacy of students with emphasis on Black students
12	Characterizing high school students' systems thinking in engineering design through the function-behavior structure (FBS) framework –	Lammi (2011)	Dissert.	HS	System thinking Higher order cognitive thinking skills
13	Achievement outcomes of Project Lead The Way: A study of the impact of PLTW in Iowa	Schenck & others (2011)	Report – Longitudinal study	MS-GTT & HS	Math achievement Female interest in mathematics College enrollment
14	Intrinsic and extrinsic factors that impact the retention and completion of African-American male and female high school students in the pre-engineering program: Project lead the way. –	Green (2012)	Dissert.	HS	Retention of female students in pre-engineering PLTW program Confidence and interest of female HS students
15	The implementation by Indiana teachers of nine key areas of LEED principles within the "project lead the way" civil engineering and architecture course. –	Smiley (2013)	Dissert.	HS - CEA	PLTW curriculum outcomes
16	Going and Passing Through Community Colleges: Examining the Effectiveness of Project Lead The Way in STEM Pathways	Starobin & others (2013)	Report	HS E	Persistence in postsecondary institutions STEM major enrollment in college
17	Project Lead The Way Students More Prepared for Higher Education –	Overschelde (2013)	longitudinal Research study	MS & HS	Math achievement College readiness Enrollment in higher education institutions
18	Using Propensity Scores to Evaluate Education Programs. Indiana University Purdue University-Indianapolis. –	Pike (2014)	Conf. proceedings	HS	Enrollment in 2 or 4 years institutions Enrollment in STEM or engineering related fields Persistence to the second year of college.

MS → Middle School Gateway To Technology Program
HS → High School Engineering or Pathway to Engineering Program
DM →Design & Modeling PLTW middle school unit

IED → Introduction to Engineering
POE → Principals of Engineering
CEA → Civil Engineering Architecture
AR → Automation and Robotics

Appendix H: Key Communications with the School

The following email was sent on August 27, 2014 to the school principal, and teachers.

PLTW research at [redacted] Middle School

From : Rula Hashem <rhashem@emich.edu> Wed, Aug 27, 2014 10:04 AM
Subject : PLTW research at [redacted] Middle School 2 attachments
To : [redacted]
Cc : John Dugger <jdugger@emich.edu>, Rula Hashem <rhashem@emich.edu>

Dear Mr. [redacted]:

I hope you have had a good summer and your Fall preparations are going smoothly. Thank you again for agreeing to help with this important research effort. Please read the attached letter which explains the research and the instructions of running the test online.

Please let me know if you have any questions or suggestions. Also, I am willing to come to your school to explain these instructions and/or help you setup the computers and administer the test before and/or during the test. Just let me know what day/s and times you want me to be there.

Again, I appreciate your willingness to support this research.

Regards,

Rula Hashem,M.A.

The next Appendix contains the attached instruction letter accompanying the above email.

Appendix G: Instructions to Teachers for Administrating the Test

Instructions for administrating the test

The following is provided to ensure that we are on the same page in relation to the research.

1. Selected students in the sixth- and seventh-grades will be participating in the study.
2. All sixth grade students who are enrolled in the PLTW Design and Modeling unit during the Fall semester will be asked to participate in the study (6 sections of 30 students each) at the beginning of the semester.
3. 60 students from sixth grade who are NOT enrolled in the PLTW unit during the Fall semester will be recruited as a control group and they will participate in the study during the first semester as well (at the beginning and at the end of the semester).
4. All seventh grade students who are enrolled in the PLTW Automation and Robotics unit during the Fall semester will participate in the study (6 sections of 30 students each).
5. 60 seventh grade students who are NOT enrolled in a PLTW unit during the Fall semester will be recruited as a control group and they will participate in the study during the fall semester as well (at the beginning and at the end of the semester).
6. Consent forms for parents and assent forms for students will be distributed to all students listed above during the first week of school and after they sign it, please sign on the bottom of the page where it states "Investigator or Specified Designee: ________ .." and list the date
7. A combined brief demographic survey along with the critical-thinking skills test will be administered to both PLTW and control group students (after submitting the signed forms) at the beginning of the fall semester (one to two weeks into the Fall semester).
8. The same test will be administered at the end of the Fall semester for all above-mentioned groups (January)
9. Data collection will require a full class period at the beginning and end of the PLTW unit (50 minutes).
10. I have created codes for students in different groups and sections (see attached two codes files). Please write each student name next to each code. For example, write down all students' names of the first section of Grade six students on the first page of the attached "GRADE 6 Students CODES" file. Then do the same for the second-, third-, fourth-, fifth-, and sixth-sections.

Please note that the "GRADE 6 Students CODES" and "GRADE 7 Students CODES" files contain sheets for all the PLTW sections. The first sheet in each file has 30 codes for each section. In addition, the last two sheets of each file contain codes for sixty Non-PLTW group students. If possible, use the order of PLTW sections according to the time taught. For example SEC 1 is for the first period where PLTW is taught, and SEC 6 is for the last period where PLTW is taught).

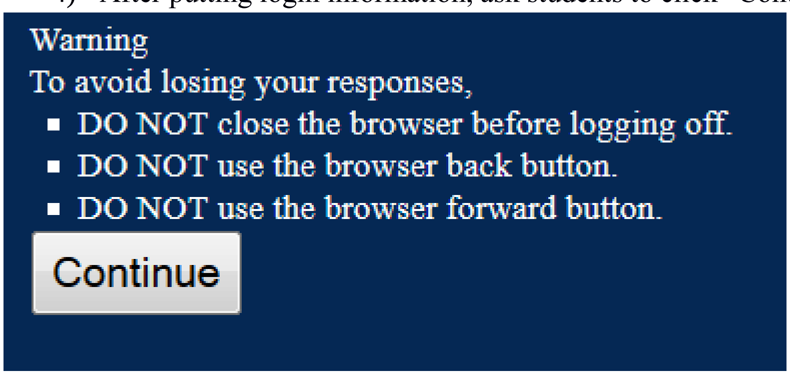
Note that all documents mentioned above are attached to this email in a zipped folder. Please use this last version of documents since they are the most updated (only slight changes compared to the previously sent documents).

In order to administer the test, do the following:

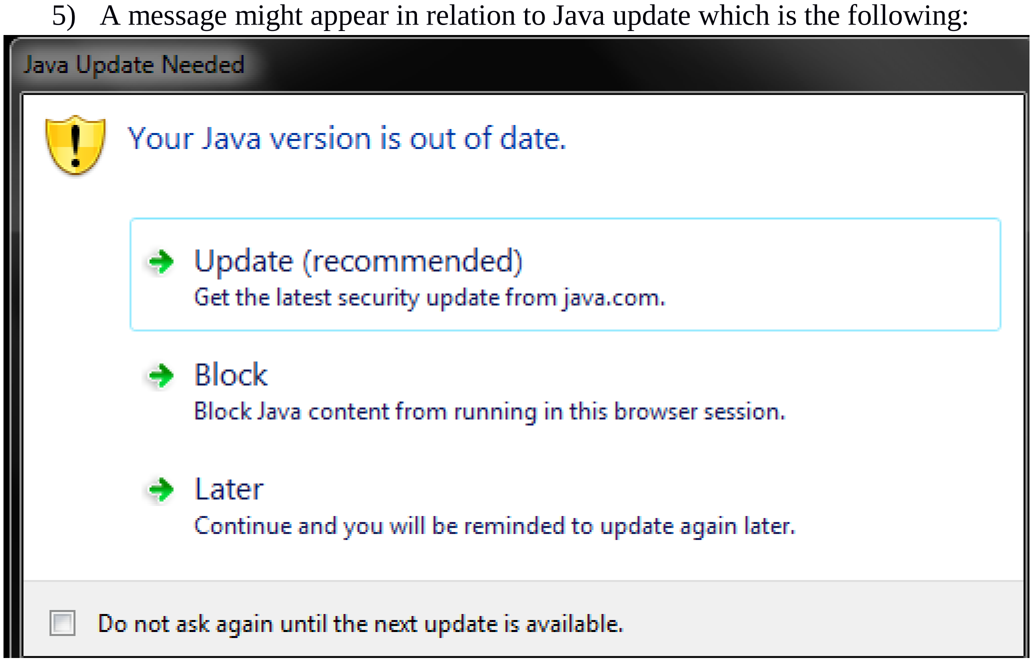
1) Go to https://members.insightassessment.com
2) Click on "Test Takers Login":
3) Use the following login info:

Username: pretPLTW
Password: pretesto

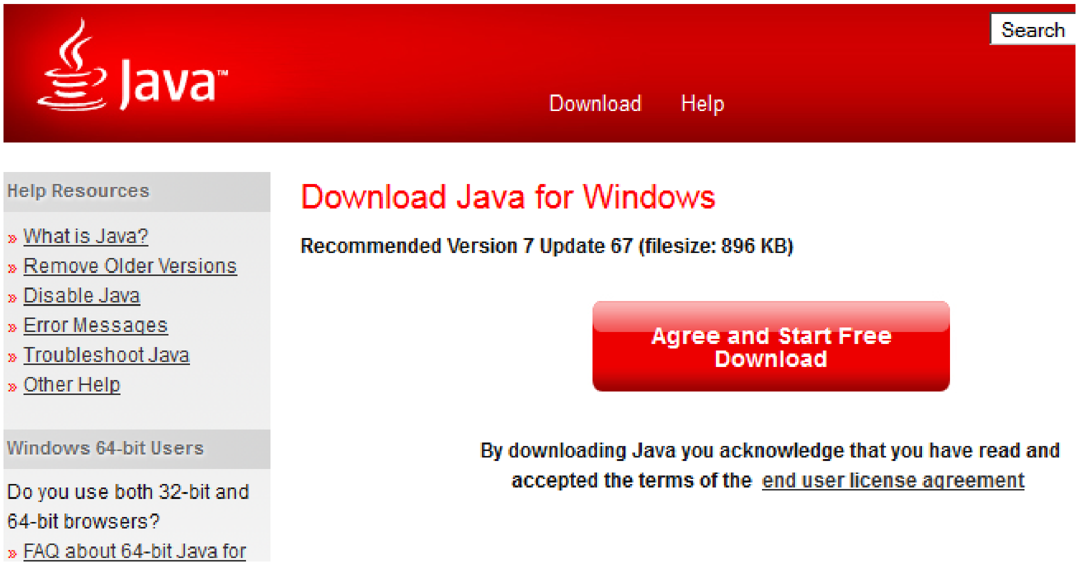
4) After putting login information, ask students to click "Continue". This is what they see.



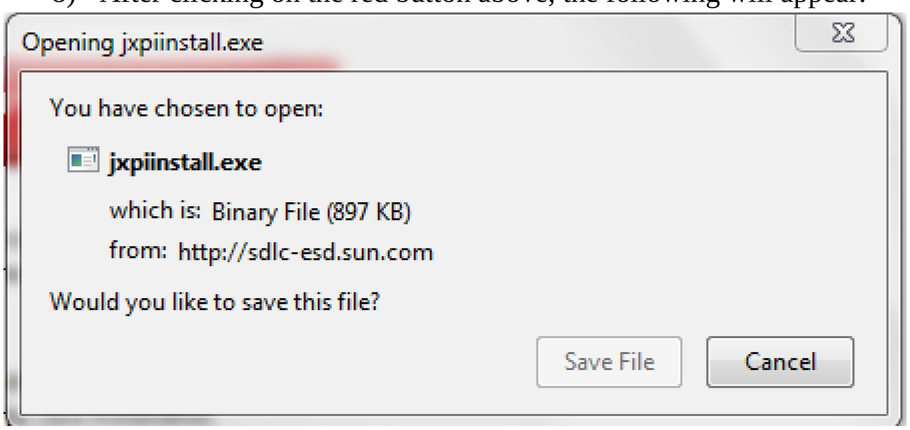
5) A message might appear in relation to Java update which is the following:



6) Click the first option "Update (recommended)"
7) You will be directed to the "Java Update website"



8) After clicking on the red button above, the following will appear:



9) Click on "Save File"
10) Open the file from your browser or your Download folder and run it.
11) Click on install, then uncheck any additional browsing or searching tools offered by Java (there is no need to change your search engine).
12) Complete installation (they may ask you to close Firefox at this time, please do so to complete installation).
13) After filling the initial demographic information, instruct students to click on "Save Profile" which is located on the top of the page
14) Then another button appears, click on "Continue"
15) I recommend asking the participating students to ask their parents about their education, their degree, and their job since not all students know that information. This should be done before the day they are taking the test.
16) I suggest also giving students their identification numbers on the day before and asking them to record it in their notebook in order to use it on the day of the test. You could give the students copies of the identification codes sheet and/or pass it around.