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DISASSEMBLE/ANALYZE/ASSEMBLE: HOW A HANDS-ON ENGINEERING PROJECT AFFECTS HIGH SCHOOL GIRLS' SCIENCE/ENGINEERING SELF-EFFICACY, INTEREST AND CAREER CONSIDERATIONS

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DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Education at the University of Kentucky

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ABSTRACT OF DISSERTATION

DISASSEMBLE/ANALYZE/ASSEMBLE: HOW A HANDS-ON ENGINEERING PROJECT AFFECTS HIGH SCHOOL GIRLS' SCIENCE/ENGINEERING SELF-EFFICACY, INTEREST AND CAREER CONSIDERATIONS

Engineering education as part of the K-12 curriculum can be an effective instructional tool and its benefits include improved science and mathematical achievement as well as an increased interest and understanding of the engineering field, especially for female students. However, there is a serious lack of research-based engineering curriculum being used at the middle and high school levels and lessons most often rely on building or construction competitions. Over the past decade or two, many well-known colleges have implemented a reverse engineering instructional unit known as Disassemble/Analyze/Assemble projects within their introductory engineering courses. These units have been shown to improve students' understanding of mechanical and technical processes as well as increase students' engineering interest and motivation, especially for female students.

The purpose of this study is to implement at the high school level a Disassemble/Analyze/Assemble (DAA) project using computers, handheld fans, and LED lights and to determine if and how this unit affects female students' self-efficacy, science and engineering interest and career aspirations. Using Social Cognitive Theory for the theoretical framework, nine female students were chosen for the study using stratified purposeful sampling. Semi-structured interviews were conducted before and after the DAA unit. Data was analyzed using an a priori directed approach to content analysis described by Hseih and Shannon (2005).

This research study showed that the DAA unit appeared to increase female students' science/engineering self-efficacy and interest as the unit provided multiple opportunities for the students to problem solve and make cognitive connections with previously learned science concepts. Students did not show any changes in their career considerations after the DAA unit. There was no statistically significant difference between the male and female mean scores on the Purdue Spatial Visual Test: Rotations (Guay, 1976; Yoon, 2011).

KEYWORDS: Engineering Education, Science Education, Engineering Interest, Science Self-Efficacy, Science Interest

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Rationale of the Study

Women are well represented in selected science, technology, engineering and mathematics (STEM) fields such as accounting, biological sciences, agriculture and medicine. However, this is not true in fields such as computer science, physics, mathematics, engineering and economics where the proportion of degrees earned by women decreased between 2000 and 2015 (NSF, 2018). In 2016, women only accounted for 20.9% of those who received engineering bachelor's degrees (Yoder, 2018) and according to the Center for Educational Statistics, accounted for only 18% of the computer science bachelor's degrees earned in 2015. Women and minority groups need inclusion and better representation in fields such as computer science and engineering to allow for product designs and solutions which meet the needs of these populations as well as well as the needs of all users (Hill, Corbett, & St. Rose, 2010).

Jobs in the STEM fields are expected to expand in the United States by one million between the years 2012 and 2022 (Vilorio, 2014). STEM graduates are among the highest paid workers and many specialized competencies in these fields, such as complex problem solving and active learning, are also highly desired in non-STEM occupations (Carnevale, Smith, & Melton, 2011). "Women must be a part of the design teams who are reshaping the world, if the world is to fit women as well as men" (Margolis & Fisher, 2002).

Therefore, there has been a national emphasis on STEM education over the last ten years in order to increase the percentage of females and minorities represented in STEM fields, and has had limited success (Honey, Pearson, & Schweingruber, 2014).

Researchers and policy makers have also increased their effort to isolate factors contributing to the smaller percentage of women in certain STEM fields (Cech, Rubineau, Silbey, & Seron, 2011; Schunk & Usher, 2019; Shea, Lubinski, & Benbow, 2001; Usher & Pajares, 2008). Many researchers have suggested that gender differences in academic self-efficacy could have affect female career choices. At the high school and college levels, male students consistently show higher self-efficacy than female students in mathematics, computers and certain science courses (Cavallo, Potter, & Rozman, 2004; Louis & Mistelle, 2012; Pajares, 1997). Other researchers have shown male students in general have a higher self-efficacy in science and mathematics (Louis & Mistele, 2002; Pajares, 1997). This is disconcerting since self-efficacy is a predictor of performance in mathematics, science classes and science related interests (Pajares, 1997).

Spatial skills are thought to be critical for many STEM fields and are essential for success in many STEM courses at the college level (Shea, Lubinski, & Benbow, 2001; Sorby, Oppliger, & Boersma, 2006). Unfortunately, studies have shown gender differences, where male students outperform their female counterparts in spatial testing, especially with mental rotation skills (Casey, Nuttal, & Pezaris, 2001; Fennema & Tartre, 1985; Linn & Petersen, 1985). Fortunately, spatial skills are moderately malleable and can be improved upon an average of a half a standard deviation through various training and instructional methods (Feng, Spence & Pratt, 2007; Hsi, Linn & Bell, 1997; Sorby, 2012; Uttal et al., 2013).

Also, interest in science and engineering differs by gender, and as students move from high school to college, more female students who had previously expressed in interest in science or engineering decide to major in another field (Sadler, Sonnet, Hazari,

& Tai, 2012). The same is true in the transition from middle school to high school. At the end of middle school, 39.5% of male students showing interest in STEM careers and only 16% of female students. This number remains stable for male students throughout high school but falls to 12.7% for female students (Sadler et al., 2012). Other researchers have also shown a significant drop in girls' interest in science at the end of middle school (Maltese & Tai, 2011).

Engineering Education

Researchers have proposed that engineering education be used at the K-12 level as an educational tool to address these gender differences and possibly increase female and minority representation in the STEM fields (Dennis, Wilson, Boyson & Kasmarik, 2019; Lawrence & Mancuso, 2012). Teaching engineering as a part of the K-12 curriculum can be an effective educational tool to integrate the STEM subjects and reflect the extent which they are interconnected in real world situations (Moore, Glancy, Tank, Kersten, & Smith, 2014). According to *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* (Katehi, Peterson & Feder, 2009), advantages of engineering education include an improved achievement in mathematics and science, increased technological literacy and an increased interest and understanding of the engineering field. Students who had either pre-engineering or technology classes in high school or informal engineering learning experiences or hobbies were shown to have a higher self-efficacy as first year engineering students, and is another validation of the importance of K-12 engineering education (Fantz, Siller, & DeMiranda, 2011).

K-12 Engineering Standards

Next Generation Science Standards (NGSS) has increased the role of engineering education by "raising engineering design to the same level as scientific inquiry in science classroom instruction at all levels and by emphasizing the core ideas of engineering design and technology applications" (NGSS Lead States, 2013, Executive Summary, p.1). In 2000, the International Technology Education Association released *Standards for Technological Literacy: Content for the Study of Technology*, which includes the standard for students to understand engineering design (Dugger, 2000). The National Council of Teachers of Mathematics (NCTM) includes developing spatial skills and rotations as part of the middle school geometry standards (NCTM, 1989).

Even though the National Academies of Sciences, Engineering, and Medicine have decided against content standards for K-12 engineering education at this time, the committee advocates for improvement in the quality of K-12 engineering education and curriculum (National Research Council, 2010). Even so, several states have implemented K-12 engineering standards of their own, of which Massachusetts was the first (Williams, McCulloch, McMahon & Goodyear, 2016).

Difficulties in implementing K-12 engineering education persists. There is a severe lack of research-based engineering curriculum (Singer, Ross, & Jackson-Lee, 2016). Even with the instructional material that has been developed, there is minimal professional development to ensure that teachers implement the curriculum with needed knowledge and capabilities to feel confident (Katechi, Pearson, & Feder, 2009). Another hindrance is that engineering projects often emphasize competitions which do not allow for students to reflect on learning goals or make science connections. These projects often do not result in the mastery of science or engineering skills (Sadler, Coyle, & Schwartz, 2000).

Disassemble/Analyze/Assemble projects

For the past two decades, disassemble/analyze/assemble projects (DAA) have been used in college engineering courses, usually in freshman or sophomore level classes (Booker, 2011; Lamancusa, Jorgensen, Kumar, & Torres, 1996; Smith & Tjandra,1998; Wood, Jensen, Bezdek, & Otto, 2001). DAA refers to the educational process patterned after the industry practice often referred to as reverse engineering or product dissection. Its purpose is to give students learning opportunities by systematically disassembling a product in order to further understand its mechanical, technical and physical properties before reassembling the product (Ogot & Kremer, 2006).

When a DAA project was compared to traditional teaching methods in a college introductory engineering course, the DAA method showed a higher transferability of knowledge with the redesign task, as well as higher ratings of learning, helpfulness and enjoyment (Dalrymple, Odesma, Sears, & Evangelou, 2011). Product dissection activities in college introductory engineering classes increase retention of mechanical and technical learning objectives as well as increasing motivation for continued learning (Calson, Schock, Kalsher, & Racicot, 1997). DAA activities provide hands-on science learning opportunities that also allow for spatial skills training (Barr, Schmidt, Krueger, & Twu, 2000; McKenna, Chen & Simpson, 2008). These activities also have been shown to increase curiosity and manual dexterity (Beaudoin & Ollis, 1995; Hess, 2000).

Theoretical Framework

Social Cognitive Theory (SCT) views knowledge and the human mind as active, creative and self-reflective (Bandura, 1999). According to SCT, learning is not a passive process, but the learner has agency. This means that the learner has influence and a proactive self-regulatory capacity with intentionality and forethought over what and how they learn (Bandura, 2001; Bandura, 2008). Learning requires attention, retention and motivation (Bandura & Jeffery, 1973). A learner acquires knowledge with a triad reciprocal causational relationship between personal, environmental and behavioral components, which interact continuously and forms the foundation of a person's ability to self-regulate (Bandura, 1986).

There are three key components of learning for SCT: self-efficacy, observational learning and outcome expectations (Bandura, 2001). According to Schunk (1991), self-efficacy is an individual's judgement of his or her capabilities to perform given actions" (p. 207). A key component of self-efficacy is agency, a person's belief that they have control over how they perform and learn (Graham & Weiner, 1996). Self-efficacy is complex, dynamic, and includes four components that provide direct influence on a person's self-efficacy beliefs: mastery experiences, social persuasion, vicarious experiences and psychological mood (Pajares, 1997). Britner and Pajares (2006) found that mastery experiences were able to strongly predict self-efficacy.

Observational learning is a common avenue to obtain new information or master an unfamiliar skill. According to SCT, individuals learn both by participating in an activity and by observing the skills and behaviors of others (Schunk & Zimmerman, 1997). Education can occur vicariously as adults or children benefit from the behavior of models they hold in high esteem and these models can also motivate others to seek a similar path as their own (Bandura, 1989; Schunk & Usher, 2019; Zimmerman, 1990).

Lastly, outcome expectation is the third key component to learning in SCT. A person perceives different potential outcomes by using their self-efficacy beliefs of their ability and skills to participate in a specific task or performance (Bandura, 1997). If a person expects positive outcomes, they are more likely to be motivated and set goals for future tasks and performances (Bandura, 1997). Positive outcome expectations may increase a person's interest in the subject matter and the desire to seek further knowledge (Schunk & Pajares, 2002).

Statement of the Problem

Engineering education is being used at the K-12 level to integrate the teaching of STEM subject matter, increase technological literacy, and increase interest in engineering (Moore, et al., 2014) and is an integral part of the Next Generation Science Standards (Lead States, 2013). However, there is a lack of research-based engineering curriculum and instructional material (Singer, Ross, & Jackson-Lee, 2016) and professional development to ensure teachers are able to implement the materials in a capable and knowledgeable fashion (Katechi, et al., 2009).

At the college level, research has shown that reverse engineering and DAA projects provide important spatial skills training needed for engineering design tasks (Barr, et al., 2000), provides students an opportunity to gain understanding of mechanical and technical processes (Sheppard, 1992; Wood, et. al., 2001) and increases female students' desire to continue pursuing engineering as a career (Beaudoin and Ollis, 1995). However, the research does not include the examination of the effects of these projects on students who had not previously considered engineering as a career option or on pre-college students. Online lesson plans for K-12 teachers to use in the classroom exist for reverse engineering or product dissection projects, but they lack research (Singer, et al., 2016).

Therefore, there is a need to implement and research DAA projects at the high school level to determine how they can benefit all students. Since this a relatively unexplored area, an in-depth examination of female high school students' experiences is the preferred choice of research to assess the contributions of a DAA project on female high school students. Using students in a high school technology course is a good avenue for exploring how this hands-on engineering unit provides benefits for female students.

Purpose of the Study

The purpose of this study is to determine how a DAA hands-on engineering unit affects female high school students' science and engineering self-efficacy, interests, and their consideration of engineering as a future career choice. This research project is a mixed methods study and will investigate nine female technology students attending a public high school. On the first day of the project, students work in groups to disassemble and reassemble computers while learning about the internal components and their purposes. At the end of that class period, students have a spatial lesson on orthographic drawings and use interlocking cubes to complete an assignment. The next class period, students will disassemble, assess, and assemble a small LED flashlight and a handheld fan and return them to working order.

Nine female students will be interviewed before and after the DAA unit using a semi-structured interview protocol. Questions were chosen with special consideration of SCT, self-efficacy, outcome expectation, observational learning, science and engineering interest, and career plans. A limitation of this study is that due to its emphasis on qualitative methodology, results are not generalizable. However, since this is an exploratory study of an engineering educational tool that has not been researched at the high school level, my hopes are that this study will highlight DAA projects, their educational benefits and encourage further study of the implementation of these projects. The study will address the following questions:

1. How and in what ways does the exposure to engineering skills through a Disassemble/Assess/Assemble (DAA) hands-on engineering unit impact high school girls' science/engineering self-efficacy and interest?

2. How does an engineering DAA hands-on engineering unit affect high school girls' consideration of a career in either science or engineering?

3. How does the impact of being exposed to engineering skills through a DAA hands-on engineering unit differ among female high school students whose scores on the Purdue Spatial Visual Test (PSVT:R, Guay, 1976; Yoon, 2011) are either above average, average or below average?

4. Do female students who have elected to take computer courses in high school show differences in spatial rotation skills as compared to their male counterparts on the Purdue Spatial Visualization Test (PSVT:R, Guay, 1976; Yoon, 2011)?

Chapter II: Literature Review

Social Cognitive Theory

Social Cognitive Theory Overview

Social Cognitive Theory (SCT) is a learning theory based on the idea that knowledge and the human mind as something more than just a conglomeration of discrete facts. According to Bandura (1999), "the human mind is generative, creative, proactive and self-reflective, not just reactive" (p. 23). Knowledge is represented within the mind in symbolic form as the embodiment of events and their significance in relation to others (Bandura, 1997). These symbols can also be regarded as codes, occurring both visually and verbally (Pajares, Prestin, Chen, & Nabi, 2009).

Learning requires more than just the passive absorbing of knowledge. Instead, there are several processes included in the grasping of knowledge in SCT: attention, retention, and motivation (Bandura & Jeffery, 1973). For example, students may pay attention and concentrate more fully on information presented by a model that is valued or seen as interesting or novel. Motivation involves the setting of personal goals that requires persistence until a specified level of performance is obtained (Zimmerman, 1990).

Acquiring knowledge occurs within an interconnection that Bandura (1986) describes as triad reciprocal causation. The individual components of this relationship are personal, environmental and behavioral. This dependency is multidirectional with each piece contributing varying degrees of input. The personal component includes cognitive, affective and biological factors whereas the behavioral component includes actions the learner observes from the model. The environment aspect can include both physical and social aspects (Bandura, 1999). The interactions within the triad are continuous and establish the foundation of self-regulation (Bandura, 2008).

Human agency is the term used within Social Cognitive Theory to describe the role a learner holds within the learning process. Bandura describes agency as the influence and self-regulatory capacity that people possess over their own learning (Bandura, 2001). The process begins as previous feedback from others is used by the learner to assess their behavior (Bandura, 1989). Then, over time the process is internalized, and the learner reflects and regulates their own learning without the external feedback. Eventually the self-regulatory process becomes one that is proactive, applying intentionality and forethought (Bandura, 2008).

Self-efficacy

Three key concepts of learning for SCT are self-efficacy, observational learning and outcome expectations (Bandura, 2001). Self-efficacy is defined as a person's beliefs about their capacity "to organize and execute courses of action required to attain designated types of performances" (Bandura, 1986, p. 391). According to Schunk (1991), self-efficacy is "an individual's judgement of his or her capabilities to perform given actions" (p. 207). A person's self-efficacy beliefs are directed toward a specific task. A question on a self-efficacy questionnaire might include, "How confident are you that you can successfully…." (Pajares, 1997). According to Bandura (1997), a key component of self-efficacy is agency, a person's belief that they have control over how they perform and learn. With that in mind, self-efficacy pertains to the belief for success in future events, rather than a focus on past achievements (Graham & Weiner, 1996).

On the other hand, self-confidence is a more general construct and is not specific to a task. It often includes a feeling or belief in one's self-worth regarding a given construct or domain (Pajares, 1997). Marsh, Walker, and Debus (1991) posited that self-concept is based on social comparisons and requires a frame of reference. People compare their performances to those of their peers and use this result to judge their own abilities. A typical self-concept item on a survey might be, "How good are you at mathematics?" (Marsh et al., 1991). Bandura (1997) also highlights that self-confidence does not include the role of agency as compared with self-efficacy.

Self-efficacy is complex and dynamic. "What people know, the skills they possess, or what they have previously accomplished are not always good predictors of subsequent attainments because the beliefs they hold about their capabilities powerfully influence the ways in which they will behave" (Pajares, 1997, p. 2). In other words, even though a person may experience authentic and successful experiences, this still does not guarantee a robust sense of self-efficacy (Bandura, 1997). The way a person interprets their performance attainments is often of greater importance than the proficiency of the performance itself (Pajares, 1997).

Self-efficacy can be seen when individuals construct beliefs about their ability to participate and perform in a given pursuit. Using these beliefs and forethought, this person imagines possible outcomes, a process called outcome expectation. If that person expects positive outcomes, then they are likely to set goals for future tasks and performances, which in turn increases their interest and they seek further knowledge of the subject. If they expect a negative outcome, the individual might reject participating in those specific tasks or at least avoiding them when possible (Bandura, 1997). Once an individual completes a task, a personal evaluation and perception of the performance is generated further informing their self-efficacy. From there, cognitive choices are formed that may include goals for tasks that contain either more or less difficulty. Building a healthy self-efficacy "involves acquiring the cognitive, behavioral, and self-regulatory tools for creating and executing effective courses of action to manage ever-changing life circumstances" (Bandura, 1997, p. 80).

Pajares and Miller (1994) studied 350 undergraduate students (229 women, 121 men) at a large public university comparing self-efficacy to self-confidence with respect to problem solving capabilities. These students were enrolled in classes within the school of education, though their majors were varied. By using the statistical method of path analysis, the Pajares and Miller study found that differences between students with regard to their problem-solving skills were due to their self-efficacy beliefs. However, when analyzing their mathematical self-confidence or their belief in the usefulness of math, neither showed a statistical relationship to students' problem-solving skills. Another study by Mone, Baker and Jeffries (1995) examined 101 women and 114 men who were enrolled in a management course at a western university. Their study showed that self-efficacy predicted personal goals and performance better than self-esteem.

Motivational researchers have determined that there is a correlation between self-efficacy and academic motivation and performance (Schunk & Pajares, 2002). In high school, there is also a correlation between science achievement and self-efficacy. In a study performed by Pajares (1997) science self-efficacy was a better predictor of performance in science class as well as science interest than gender, ethnicity and parental background. In college, science self-efficacy is a strong indicator to whether or not a person will persevere in a science related major (Andrew, 1998). In a study performed by Britner and Pajares (2006) on middle school students, science self-efficacy scores were the best predictor of grades in the science classroom. “Higher self-efficacy… creates feelings of serenity in approaching difficult tasks, increases optimism, lowers anxiety, raises self-esteem and fosters resilience” (Schunk & Pajares, 2002, p. 19).

Observational Learning

The second key concept for learning in Social Cognitive Theory is observational learning, which is a common avenue used to obtain new information or master unfamiliar skills. From an early age, much of children’s education occurs as they engage in social relationships (Bandura, 1989). According to SCT, individuals learn both by participating in an activity and by observing the skills and behavior of others (Schunk & Zimmerman, 1997). A person is also more likely to model behavior or skills observed in an individual with whom they identify (Schunk, 1989). This modeling significantly influences, prompts, inhibits and shapes one’s values and behavior to form reality (Bandura, 2001). Education occurs vicariously as both children and adults benefit from behaviors being modeled by those who are valued or held in high esteem. This observational learning allows a person to understand the rewards and punishments for various behaviors without the need to physically participate in each and every experience (Bandura, 1989; Zimmerman, 1990). Also, a model or mentor who has attained success and rewards in school or in a chosen career can motivate others to pursue similar paths (Schunk & Usher, 2019).

Outcome Expectation

Outcome expectations is the third key component to learning in Social Cognitive Theory. It is the perception a person has of the different potential outcomes of a given task, performance or set of skills (Bandura, 1993). They are strongly connected to and directly affected by self-efficacy. Self-efficacy can be seen when individuals create beliefs about their ability to participate and perform a specific pursuit. Using these beliefs and forethought, this person imagines possible outcomes, a process called outcome expectation. If that person expects positive outcomes, then they are likely to set goals for future tasks and performances, which in turn increases their interest and they seek further knowledge of the subject. If they expect a negative outcome, the individual might reject participating in those specific tasks or at least avoiding them when possible (Bandura, 1997). Once an individual completes a task, a personal evaluation and perception of the performance is generated further informing their self-efficacy. From that point cognitive choices are formed that may include goals for tasks that contain either increased or decreased difficulty. Building a healthy self-efficacy "involves acquiring the cognitive, behavioral, and self-regulatory tools for creating and executing effective courses of action to manage ever-changing life circumstances" (Bandura, 1997, p. 80).

Self-Efficacy Components and Effects on Learning

Bandura and Social Cognitive Theory states that there are four main areas that provide a direct influence on self-efficacy beliefs. The first of those is enactive mastery experiences, and due to the authenticity of these experiences, they are considered to have the greatest impact on self-efficacy (Bandura. 1997). Authenticity is an essential ingredient and it is not possible to have a lasting impact on self-efficacy with empty verbal praise and unchallenging tasks. Mastery experiences are also a key component to the development of interest in a specific endeavor or subject matter (Bandura, 1997). Britner and Pajares (2006) found that mastery experiences were able to strongly predict self-efficacy. “The development of cognitive competencies requires sustained involvement in activities. If appropriately structured, such pursuits provide the mastery experiences needed to build intrinsic interest and a sense of cognitive efficacy when they are lacking” (Bandura, 1999, p. 217).

The second component that can affect self-efficacy beliefs is called social persuasion. This includes encouragement and praise given by teachers, parents or role models. In studies, social persuasion has been shown to be more important to females in general than to males (Usher & Pajares, 2008). These social persuasions do not only encourage but also have the power to empower. Parents and teachers can play an important role to help students continue to persevere when they feel discouraged. Often, social persuasion is a factor in students who pursue a career path in order to please a parent or family friend (Miller, Blessing, & Schwartz, 2006). Male teachers as well as female teachers can have a significant positive effect on students’ self-efficacies. Many teachers have lasting effects on girls as they encourage them to learn, explore and to be curious. Then, as their math and science self-efficacies increase, they are willing to take more difficult math and science courses (Zeldin & Pajares, 2000). Persuasion can also have profound negative effects at times such as poor assessments, criticism, or just a poor choice of words (Britner & Pajares, 2006). Sometimes lack of confidence in a person’s skills is communicated more subtly but nonetheless is very damaging to perceived self-efficacy (Bandura, 1997).

The third category affecting self-efficacy is vicarious experiences. One such experience is through modeling and comparison. Vicarious experiences are those where we compare our abilities to someone else, or we can see ourselves attaining a goal because we have seen others like us attain that same goal (Bandura, 1997). Students constantly compare their progress to others around them. A lower score than the norm diminishes a person's belief in their capability and a higher score produces a feeling of superiority, even if the given scores and norms are completely false (Bandura, 1997). Also, students watch others that they consider as having similar abilities to themselves achieve or have success in a particular event or activity and determine that they would also be able to accomplish that same goal. This is common as students determine which fields of study or careers they should pursue (Pajares, 1997).

Vicarious experiences would include the influence of role models. It is important for female students to see mathematics and science role models whether they come from female scientists discussed in their textbooks or a female biotechnical engineer that lives next door. Even though this category may not have as large of an influence as the other two, it does make a difference for students to see successful women go before them in similar career choices. It can reduce the feeling of isolation and gives a sense of hope as they know other women have successfully forged the path ahead (Bandura, 1997). Female scientists and engineers could be an important motivator for girls, especially at the middle school age and should be brought into the science and mathematics classrooms to interact with students (Britner & Pajares, 2006).

Vicarious experiences are those where we compare our abilities to someone else, or we can see ourselves attaining a goal because we have seen others like us attain that same goal (Bandura, 1997). Female mathematics and science models can be important in the classroom, especially for those students who do not have female science and math role models in their family. Female modeling is especially important in those areas that have been traditionally male-dominated fields (Zeldin, Britner, & Pajares, 2008). Students can also use themselves as a model instead of comparing themselves to others. Besides competing with themselves, students can also coach themselves by envisioning successes during difficult tasks or challenging courses. Envisioning positive outcomes may increase the motivation that is needed to be successful at the given task (Bandura, 1997).

The last category that has an impact on self-efficacy is psychological mood. This would include mathematics or science anxiety and test-taking anxiety. Fear and dread keep students from learning and experiencing classroom activities to their fullest. Positive moods and optimism can play an important role in self-efficacy and interest in a particular subject matter. If science and mathematics material is taught in a creative and fascinating way, students are more likely to be engaged and have positive attitudes toward learning (Bandura, 1997). When a person feels relaxed and comfortable about a given task or challenge, often their perceived self-efficacy is higher. If that same person feels stressed about a situation, this can lead to feelings of being less capable of accomplishing the task ahead (Bandura, 1997).

Self-Efficacy Research

Quantitative Self-Efficacy Research

Self-efficacy has been connected to various components of academic success. For example, research studies have shown an important relationship between self-efficacy, persistence, and the ability to overcome obstacles. Bouffard-Bouchard, Parent and Larivee (1991) studied 45 junior high students and 44 high school students to determine the role of self-efficacy on written comprehension problems focusing on contextual references. Their study showed that regardless of cognitive level, those students with a higher self-efficacy belief in their ability to solve the problems regulated their time more efficiently and had greater task persistence than those with lower self-efficacy. Skaalvik, Federici, and Klassen (2015) surveyed 823 students ranging from 8^{th} to 10^{th} grade in Norway. They found a positive correlation between mathematics self-efficacy and intrinsic motivation, effort and persistence.

Goal setting is another essential skill that can lead to academic success. Zimmerman, Bandura, and Martinez-Pons (1992) researched 9^{th} and 10^{th} grade students to determine the relationship between self-efficacy and goal setting. Their study included 102 high school students (50 boys, 52 girls) from a variety of backgrounds and ability levels. They found that the students with higher self-efficacy set higher goals for themselves and were more likely to attain those goals than students with lower self-efficacy beliefs. Bandura (1997) noted that a student will a lower self-efficacy is less to see themselves as successful in a more challenging situation even when they have the skills to be successful (Bandura, 1997).

Motivational researchers have determined that there is a correlation between self-efficacy, science achievement, and academic performance (Britner & Pajares, 2001; Britner & Pajares, 2006). Hackett and Betz (1989) conducted a research study with 262 (153 women, 109 men) undergraduate college students at a Midwestern university. They found that math self-efficacy predicted mathematics-based career better than either past math achievement or current performance in mathematics. Pajares (1997) also showed that science self-efficacy is a good predictor of performance in science class and science related interests.

A person's self-efficacy plays an important role in their ability to acquire new skills. Mitchell, Hopper, Daniels, George-Falvy, and James (1994) researched the connection between self-efficacy and the learning using complex computer tasks that simulate the skills performed by air traffic controllers. Studying 110 undergraduate students (56 men, 54 women), they found that for the acquisition of a new skill, self-efficacy was a better predictor of performance than the students' own judgements of expected scores.

Self-efficacy plays a role in college success for freshman students. Chemers, Hu, and Garcia (2001) studied first year college students at a California University using structural equation modeling from the data obtained from questionnaires of 78 male and 295 female students. They found self-efficacy to be a significant indicator for first year college success both through a student's academic performance and their adjustment to the college experience.

Skaalvik, Federici, and Klassen (2015) found a positive correlation between a person's math self-efficacy and their willingness to seek help. Karabenick and Knapp (1991) noticed while researching 396 undergraduate students that those students with lower self-efficacy were less likely to seek help formally and informally. Their study also found a connection between low self-efficacy beliefs and the tendency to view help-seeking as threatening rather than a beneficial step.

Math self-efficacy not only affects academics but also plans for future math courses (Eccles & Jacobs, 1986). Those students with a lower self-efficacy often do not take the more difficult mathematics and science classes because they don't see themselves as capable of doing well. They may even feel that they are not capable of doing well even if they did devote themselves to working hard (Pajares, 1997).

According to Schunk and Pajares (2002), students avoid those areas of study where they feel less confident and are less likely to persevere during times of discouragement and difficulty. They tend to be easily discouraged which can produce self-fulfilling prophesies and they do not perform to the level they are capable. Students with a lower self-efficacy can believe that the challenges they face are more difficult than they are. These students also have more difficulty dividing an overwhelming task into more manageable pieces (Schunk & Pajares, 2002). "If students do not have the confidence to work through a difficult task, how will they be the innovative leaders of the future" (Bergin, 2013, p.2)

Males in general have a higher self-efficacy in science and mathematics than females (Louis & Mistelle, 2012; Pajares, 1997). Even when women enter engineering at highly respected engineering schools like Massachusetts Institute of Technology, Stanford University, or Cornell University, they still have a significantly lower self-assessment of their mathematical abilities (Cech, Rubineau, Silbey, & Seron, 2011). Cavallo, Potter and Rozman (2004) researched non-physics majors throughout an inquiry based yearlong introductory physics course. They found that for both male and female students, self-efficacy predicted both physics understanding and achievement. The study also found that the female students consistently showed lower self-efficacy than the male students. Bryan, Glynn, and Kittleson (2011) noted that even though high school girls who intended to take AP science courses had the same self-efficacy as their male counterparts, this was not true of girls who did not intend to take AP science courses. When comparing male and female students who did not intend to take AP science courses, girls had a lower science self-efficacy that the boys (Bryan, et al., 2011).

Qualitative Research in Self-Efficacy

Self-efficacy researchers have primarily used quantitative methodology for their research studies. According to Usher (2009), most qualitative self-efficacy research has been at the college level and many of these studies investigate the effects of teacher self-efficacy. More qualitative research at the K-12 level is needed to more closely examine conditions in a student's life by which they judge their experiences to inform their self-efficacy beliefs (Usher, 2009). "Qualitative investigations hold great promise for providing a rich understanding of the genesis of students' self-efficacy beliefs" (Usher & Pajares, 2008, p. 784).

Usher (2009) used qualitative methodology to research middle school self-efficacy beliefs and sources in order to validate Bandura's proposed sources of self-efficacy. She interviewed eight middle school students with either high or low self-efficacy beliefs. She also interviewed the teachers and parents of these students. The study showed that students relied on all four of Bandura's proposed sources of self-efficacy (mastery experiences, vicarious experiences, verbal persuasion, and psychological mood). Those students with high self-efficacy referred to early mathematical successes in school as important to their self-efficacy beliefs. The boys with higher self-efficacy beliefs were more apt to attribute their mathematics successes to innate ability where the girls were more apt to mention diligence and hard work. Those students with lower self-efficacy referred to mathematics becoming more difficult or suddenly becoming difficult for them in middle school. Those with lower self-efficacy compared themselves negatively with their peers and described feeling like they were the only one in class who did not “get” math (Usher, 2009).

In a qualitative study by Zeldin and Pajares (2000), fifteen women who excelled in STEM careers were interviewed with respect to their self-efficacy beliefs and sources. For these women, verbal persuasion and vicarious experiences were a vital force for developing and maintaining a healthy self-efficacy. Their self-efficacy beliefs helped them to be resilient when they were faced with both academic and social obstacles. Most of these women in this study had family members with careers that required a high level of mathematics (Zeldin & Pajares, 2000).

Another qualitative study compared self-efficacy sources and beliefs of men and women in STEM careers (Zeldin, Britner & Pajares, 2007). The primary sources of self-efficacy for the men were mastery experiences, which included their interpretations of their success and achievements. However, the women relied more heavily on relational experiences relating to their self-efficacy which provided them with needed support to be able to successfully navigate primarily male-dominated fields.

STEM and Gender

STEM and Female Representation

Women are represented in STEM fields to varying degrees. Female doctors represent 47% of the 2014 graduation classes from United States Medical Schools (Kaiser Foundation, 2015). Women earned 43% of the mathematics and statistics degrees and represent 60.9% of all accountants and auditors in the United States. In 2011, women were half of the newly hired accountants and represent 40% of all Certified Public Accountants in the US. 58% of the undergraduate degrees in biology were earned by women.

However, the statistics are grim in other STEM fields. In 2012, only 19.2% of engineering bachelor's degrees were awarded to women (NSF, 2014). Women only represented 18.2% of the computer science graduates and only 19.1% of the physics graduates. Even though 18-19% of the engineers that graduate are women, only fourteen percent of working engineers are women (Census, 2014), indicating that women are either not entering the field of engineering after graduation or have chosen to leave the field at some point in their career.

STEM and Spatial Skills

There are a multitude of reasons for the poor representation of women in certain STEM fields. Some researchers have hypothesized that gender differences in spatial skills have attributed to this problem. Researchers have different definitions for what areas are included in visual-spatial ability. Maier (1994) describes 5 components of spatial skills or spatial intelligence. These include spatial perception, spatial visualization, mental rotations, spatial relations and spatial orientation. These skills are also included in the mathematical section of the ACT and SAT college entrance examinations. There are also several other common standardized tests that measure various aspects of a person's spatial skills, like the Purdue Spatial Visual Test: Rotation (PSVT:R, Guay, 1976) or the Mental Cutting Test (MCT; College Entrance Examination Board, 1939).

Research studies show that spatial ability is a critical skill for many STEM fields. In a longitudinal study by Shea, Lubinski, and Benbow (2001) the results showed that intellectual adolescents who had higher spatial skills as compared with verbal skills were more likely to become engineers or computer programmers. In a study spanning over eleven years and 400,000 high school students, Wai, Lubinski and Benbow (2009) found that "spatial ability is a salient psychological characteristic among adolescents who subsequently go on to achieve advanced educational and occupational credentials in STEM" (p. 827). The study also showed that spatial ability was able to significantly predict STEM achievement. Hamlin, Boersma and Sorby (2006) found that a person's spatial skills are related to their ability to effectively learn to use computer aided design software, which is essential for engineering and architecture careers.

The American Society for Engineering Education consider spatial skills, which include the ability to sketch freehand engineering objects as well as being able to create 3-D solid objects using computer software, as essential engineering skills (Barr, 2004). Spatial skills are necessary for several different engineering fields, but is especially important for civil engineers (Alias, Black, & Gray, 2002; Dorta, Saorin & Contero, 2008). According to Wu and Shah (2004) chemistry requires visual and spatial thinking and students need the ability to visualize transformations between two dimensional and three-dimensional objects.

Gimmsestad (1990) studied 11 variables to find their relationship with success in the common first year engineering course, *Engineering Graphics*. His study included 300 male and 65 female students and showed that a person's score on the PSVT:R (Guay, 1976) was the most significant indicator of their success in the course. The other variables included in the study were mathematics ACT score, gender, solid geometry, experience with shop and drafting training and construction toys.

Test questions that require the usage of spatial skills have consistently over time shown the largest gender gap of any type of standardized test questions (Linn & Petersen, 1985). Boys significantly outperform girls on a vast array of spatial reasoning tests, but especially those that require mental rotation skills (Casey et al., 2001; Fennema & Tartre, 1985; Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). The rotational skills on these tests require the test taker to mentally rotate two or three-dimensional objects in a variety of positions quickly and accurately (Linn & Petersen, 1985). The results of a meta-analysis study of sex differences in spatial ability by Voyer et al. (1995) showed that the largest gender differences occurred on test questions that required mental rotation, spatial working memory, and taking two dimensional drawings and objects and transforming them into three-dimensions. Another type of spatial ability test that males routinely and significantly outscore females on is the Water Level Test (Linn & Petersen, 1985; Voyer, 1996). Students are shown bottles of varying shapes with a water line drawn. Then the student is shown a picture with the bottles turned at various degrees and they must draw the water line accurately (Linn & Petersen, 1985).

Casey et al. (2001) analyzed mathematical items from the TIMSS study US data that had the largest gender gap. Using a subset of items with the high gender gap together with statistical techniques, they were able to show that 74% of the indirect effects on the test were caused by spatial skills and 26% of the indirect effects were from mathematics self-confidence. “These results indicate that spatial-mechanical thinking is particularly useful on those types of mathematical items at which boys typically excel" (Casey et al., 2001, pp. 41-42).

Spatial skills are used for problem solving, especially by males (Gallagher et al., 2000). Gallagher et al. (2000) researched how high school students performed on problem solving tasks for standardized test questions in order to understand the gender differences in strategies used by male and female students. The questions they used were from the Graduate Records Examination (GRE), quantitative section. Items that showed the largest differences in favor of male students were those which required students to create visual representations and be able to manipulate these figures mentally.

Casey, Nuttall, and Pezaris (1997) investigated mediators for the gender gap on the SAT-M test, and to what degree did spatial ability play a role. First, "the results indicated that mental rotation skill is almost twice as influential a mediator of gender differences in SAT-M as was the measure of self-confidence" (Casey et al., 1997, p. 675). Another insight from their research is that the male advantage is mediated through two things. First, it is mediated through their mental rotation capabilities and the second is the higher self-confidence that males have while working the mathematics problems on the SAT-M test (Casey et al., 1997). As noted earlier, these tests are the backbone for college scholarship decisions, so the female disadvantage creates a high price tag for many families. Casey et al. (1997) recommends spatial training as part of every child's education.

Research has shown that spatial skills can be improved upon by various training methods (Feng, Spence & Pratt, 2002; His, Linn, & Bell, 1997; Sorby, 2012). Wilhelm, Jackson, Sullivan, and Wilhelm (2013) investigated the spatial-scientific understanding of preteen science students. The preteen female students scored considerably lower on spatial visualization pretests than their male counterparts. However, after a five-week integrated STEM curricular intervention, there was a significant increase in achievement for the girls as compared to the boys on the Geometric Spatial Assessment (Wilhelm, Ganesh, Sherrod, & Ji, 2007).

Uttal et al., (2013) performed a meta-analysis of training studies for spatial skills, including semester long courses, computer instruction and video game learning. They wanted to determine whether spatial skills were malleable and open to gains after specialized instruction is given. They reviewed 206 studies, with 45% of the studies published in journals and 56% from unpublished dissertations, unpublished data or conference articles. They determined that spatial skills are moderately malleable, and that on average, the improvement was by half of a standard deviation (Uttal et al., 2013). Their research also showed that spatial training is especially useful for STEM students with poor spatial ability scores. Several spatial training strategies were shown to be highly successful in improving spatial skills and some successful strategies were able to be integrated into standard mathematics and science curricula (Uttal et al., 2013).

Several university engineering programs have implemented various programs to better educate their freshman and sophomore engineering students in spatial skills (Hamlin, Boersma, & Sorsby, 2006; Shea, Lubinski, & Benbow, 2001; Wood, Jensen, Bezdek & Otto, 2001). For example, beginning in 1994, Michigan Tech implemented semester long classes for first year engineering students to target and improve their spatial skills (Sorby, 2012). The course is recommended, but not required, for those first-year engineering students who fail the PSVT:R (Guay, 1976) test. The classes resulted in higher GPAs for students in their engineering graphics course than those who chose not to take the course. Also, there was a statistically significant higher engineering retention rate for those women who chose to take the course, but not for the men. Her studies have also shown an improvement in science, mathematics and engineering courses for those who received spatial training (Sorby, 2012).

Female Interest in STEM and STEM Fields

Researchers have also considered whether gender differences in STEM interest could attribute to the lower numbers of women in certain STEM professions. In 2007, the Committee on Maximizing the Potential of Women in Academic Science and Engineering and the Committee on Science, Engineering and Public Policy wrote a report entitled *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Sciences*. "With each step up the academic ladder, from high school on through full professorships, the representation of women in science and engineering drops substantially. As they move from high school to college, more women than men who have expressed an interest in science or engineering decide to major in something else" (NAP, 2007, p. 2).

Sadler, Sonnet, Hazari, and Tai (2012) collected surveys from 6860 college freshman, 56.4% attending a four-year college and 43.6% attending a two-year college. "At the start of high school, a total of 39.5% of males and 15.7% of females reported career interests in STEM careers" (Sadler et al., 2012). At the end of high school, the same percentage of male students reported an interest in STEM careers, but the percentage of female students interested in STEM dropped by 19% (Sadler et al., 2012). Mau (2003) followed girls' career interests starting in 8th grade continuing forward for six years. Girls in this study were less likely than the males to persevere with their science or engineering career intentions. Of those students who had shown interest in STEM careers at the end of middle school, 70% of the male students continued to show interest at the beginning of college versus only 45% of the female students (Mau, 2003).

According to Bandura (1997), self-efficacy together with outcome expectations are the strongest indicators of interest in a subject matter. As an individual develops interest in a specific field of study or a set of skills, he or she is more likely to set goals for themselves and spend time learning or performing specific tasks. Further episodes of success and mastery experiences in that area then produce an increase in self-efficacy. The higher the self-efficacy and proficiency a person develops, the more a person will enjoy and have an interest in that area. A person's intrinsic interest in mathematics or science was the largest difference between those students who persevered with a STEM degree and those who did not (Seymour & Hewitt, 1997).

Interests and goals result from the combination of outcome expectations and self-efficacy (Bandura, 1997). Outcome expectations is the perception a person has of the different potential outcomes of a given task, performance or set of skills. They are strongly connected to and directly affected by self-efficacy, but also have influencing inputs other than self-efficacy. Turner, Steward, and Lapan (2004) found when surveying 6th graders that "math self-efficacy positively affects their math outcome expectations and that math efficacy and math outcome expectations together affect their math and science career interests" (p. 48). Lopez, Lent, Brown, and Gore (1997) showed a direct and significant relationship between interest and outcome expectations for either gender. Also, mathematics and science self-efficacy have been shown to significantly predict science and mathematics related interests for high school students (Hackett & Betz, 1989; Lent, Lopez, & Bieschke, 1993). It makes sense also that when students are highly competent in a specific subject area, they are more apt to pursue a career using those skills.

There are cases, however, where the outcome expectation, especially related to their own future, is not as strongly related to an individual's self-efficacy. It is possible for a person to have a high self-efficacy and be proficient in mathematics and science and yet not see themselves working in one of those professions. There are many reasons students do not see themselves in a STEM job. This person's dream job may be in a profession not related to science and mathematics. It is possible that this person may never have been properly introduced to fields and jobs within science and mathematics, so they do not see themselves in one of those fields. They may also have the misunderstanding that engineering, science, technology and computer science jobs are boring and performed in isolation from other people. It is also a common misconception, especially for women, that STEM professions do not emphasize social concerns or helping people (Weisgram & Bigler, 2006). It is important then, when attempting to attract more women to STEM careers to not only consider self-efficacy and math and science competencies, but also to consider the incorrect image some people have of STEM jobs. This is an area that teachers can overlook.

Female students' interests often included a desire for altruism within whatever major they chose to study in college, whether a STEM career or not (Seymour & Hewitt, 1997). Many of the girls wanted to have careers that centered on helping people, animals, or the environment (Baker & Leary, 1995; Jones, Howe, & Rua, 2000). This was true of women who were interested in the vast range of STEM and biological fields, but was often specifically mentioned when girls described wanting to be a doctor, nurse, dentist, veterinarian or pharmacist (Aschbacher, Li, & Roth, 2010; Baker & Leary 1995). Eccles (2005) states that there is evidence that girls reject certain career options that include physical science and engineering due to an incomplete understanding of the environmental and societal benefits these fields provide. A female student with high mathematical ability may prematurely remove these fields from consideration.

As researchers continue to design programs and effective strategies to improve female representation in STEM careers, it is also important to determine critical junctures in a female student's life where academic intervention could have the highest probability of exerting influence. "By far, the most dominant factor influencing engineering or science career interest at the end of high school is student interest at the beginning of high school" (Sadler et al., 2012, p.421). A student who shows interest in STEM and STEM careers during middle school is nine times more likely to express interest in a STEM career at the end of high school. If a female student shows no interest in pursuing a STEM career at the end of middle school, there is only a 9% chance that she will express an interest to pursue a STEM career at the end of high school (Sadler et al., 2012).

Engineering Education

Engineering Education and Standards

The Next Generation Science Standards (NGSS), published April 2013, include engineering design as an expected feature to be added to the curriculum (Lead States, 2013). Engineering design gives an excellent introduction to the engineering process. Reverse engineering is also an excellent tool for teaching engineering concepts. One of the integral steps of the engineering design process is redesign. Reverse engineering allows students to learn from initial well-designed products, determine possible reasons a specific design was chosen, and then discuss possible improvements to the design. Reverse engineering also allows students a hands-on approach to learn many different scientific and mathematical concepts depending on the items students or teachers chose to disassemble. The following is a quote from the Middle School Engineering Design in the NGSS:

> The focus in middle school is on a two stage process of evaluating the different ideas that have been proposed: by using a systematic method, such as a tradeoff matrix, to determine which solutions are most promising, and by testing different solutions, and then combining the best ideas into new solution that may be better than any of the preliminary ideas. Improving designs at the middle school level involves an iterative process in which students test the best design, analyze the results, modify the design accordingly, and then re-test and modify the design again. Students may go through this cycle two, three, or more times in order to reach the optimal (best possible) result (p. 53)

These recommendations are just as applicable at the high school level. Most, if not all, of these suggestions can be accomplished through a well-formulated reverse engineering project.

The National Council of Teachers of Mathematics (NCTM) considers spatial training an important aspect of middle school education and states “the mathematics curriculum for grades 5-8 should include the study of the geometry of one, two, and three dimensions in a variety of situations, so that students can visualize and represent geometric figures with special attention to developing spatial sense" (NCTM, 1989).

The Common Core Standards for Mathematics for middle school is divided into sections for modeling, geometry, algebra, numbers and quantities, statistics and probability and functions. Engineering requires mathematical modeling for many different aspects of the problem solving and design process. There are specific measurements required when drawing individual parts, and cost and constraints are always a part of the engineering process. Also, one specific aspect of the geometrical common core mathematical standards is spatial skills and rotations. The geometric drawings that are required in the project will cover both the geometric modeling and the spatial skills. Beyond the geometry, students need to be taught that engineers use mathematics throughout the engineering process as they calculate whether certain materials can handle the stresses that will be put on the material. Mathematics is key to the design process as every measurement is essential for manufacturing or systems analysis. Budgets are important and certain financial constraints need to be taken into consideration.

The National Center for Educational Research (NCER) and Institute of Educational Sciences published a practical guide entitled *Encouraging Girls in Math and Science* (Halpern, Aronson, Reimer, Simpkins, Star, & Wentzel, 2007). This guide provided classroom recommendations for teachers that they believed would improve female participation in mathematics and a variety of science fields. These recommendations are rooted in educational multiple research studies and these techniques been have shown to provide improvement in students' learning. These recommendations have been used successfully in classrooms with positive results and come highly recommended by educators and as well as researchers (NCER, 2007).

Several of the recommendations are applicable to spatial skills, engineering education and self-efficacy. One important recommendation is that girls be exposed to spatial activities which supports research in this area (Feng, Spence, & Pratt, 2002; His, Linn, & Bell, 1997; Sorby, 2012; Wilhelm, et al., 2013). Another recommendation is that teachers provide students with an environment in which they can be creative and be allowed to be curious. Students prefer a classroom that allows them to inquire, explore and discover. In a qualitative research study about gender and science, girls showed a preference to learning by hands-on experiences (Baker & Leary, 1995). "Students are more likely to experience their own accomplishments … when engaged in active, hands on learning experiences rather than passively listening to lectures" (Colbeck, Cabrera, & Terenzini, 2000, p.176). Middle school girls in the research study by Baker & Leary (1995) expressed the desire to "learn for themselves" and "figure things out". They expressed a strong desire for laboratory experiences to discover "how things work". Echoing this same feeling, another research study found that students preferred STEM lessons that were physically and visually engaging (Rowan-Kenyon, Swan, & Creager, 2012). These lessons plans should be organized in such a way that students are able to master specific skills and knowledge. Mastery experiences have a more direct and powerful effect on self-efficacy than the other three factors mentioned earlier (Bandura, 1997).

Providing female STEM role models is another key recommendation. Research studies demonstrate that for girls, self-efficacy also relies heavily on feedback they receive from people they admire and value (Britner, 2008; Usher & Pajares, 2006; Zeldin, Britner, & Pajares, 2008). One helpful strategy is for women STEM majors to help in K-12 classrooms to encourage girls and be role models. Many girls do not have firsthand exposure to women in computer science, women scientists, mathematicians, or engineers so their presence in the classroom could be very influential. Bandura (1986) talked about the importance of vicarious experiences such as role models to self-efficacy. Again, it is important to note that female students seem to be more sensitive to the influence of vicarious experiences than males, so it is important that educators help provide those experiences for girls, especially those unlikely to have those experiences within their own family (Usher & Pajares, 2006).

The last recommendation is that teachers provide frequent and targeted formative assessments to students. As mentioned earlier, mastery experiences profoundly affect self-efficacy (Britner & Pajares, 2006). Students also rely on more immediate feedback from assignments to inform their self-efficacy beliefs (Bandura, 1997). In a qualitative study by Usher (2009), students in the study with low mathematics self-efficacy rarely mentioned receiving feedback or encouragement from teachers. The girls expressed feeling less capable. These girls heavily relied on the information or lack of information they received from others (Usher, 2009).

Engineering Education in Middle and High Schools

The National Center for Engineering and Technology Education (NCETE) researched necessary elements students need for proper engineering education. First is the importance of a hands-on approach. They also explained that students need to understand the importance of mathematics behind engineering, and some people describe mathematics as the language of engineering (Childress & Rhodes, 2006). Along with the importance of mathematics, understanding mathematical modeling is extremely important in understanding engineering. Often these are key concepts that have not been included in basic design challenges used by some teaching professionals. Engineering education is important for all students P-12 to help students develop problem solving skills, spatial reasoning, understanding how objects work and the process involved in the manufacturing (Brophy, Klein, Portsmore, & Rogers, 2008).

Teachers have tried to introduce engineering concepts by introducing classrooms to design challenges. However, many of these design challenges require the building of bridges from Popsicle sticks or toothpicks. While these design challenges have merits, reverse engineering has the potential to produce more student growth mathematically and scientifically, especially in terms of real-life application for science and mathematics (Brophy et al., 2008).

Even though engineering is now to be taught as a part of the Next Generation Science Standards and can be useful to teach mathematical concepts, schools seem to be having a difficult time integrating it into their curriculum. Some schools integrate it through technology classes, which are only electives. Other schools offer special curriculums like Project Lead the Way and require specialized professional development by teachers with degrees in the STEM areas. There are also specialized clubs that are designed to teach engineering concepts after school for middle school and high school students. This only reaches a small portion of students and may leave out students interested in STEM careers but who are involved in other extracurricular activities. There are also high schools who provide pre-engineering curriculum as part of a magnet program, but again, these programs only reach a small number of students (Brophy et al., 2008).

Teachers find it difficult to keep up with changes like the addition of engineering to the NGSS and Common Core. External and costly professional development exists for teachers to learn how to teach engineering concepts. Other schools have decided to introduce engineering concepts through specialized computer simulations alone. Computer modeling is a key to the work of engineers of the twenty first century, and those students who major in engineering will be required to master certain computer programs. However, for middle and high school students, seeing and manipulating actual products is more engaging and induces more curiosity about how things work. Students can feel disconnected when engineering design projects only happen through computer simulations. Holding specific parts and manipulating them in a concrete way is an important aspect of spatial awareness development (Wood, Jensen, Bezdek, & Otto, 2001).

Childress & Rhodes (2006) used focus groups of existing engineers, engineering educators, and those who worked closely with engineers and engineering educators to gather recommendations for the future direction of engineering education in grades 9 through 12. Reverse engineering was stated as an important aspect of engineering to help encourage students' ability to analyze. Reverse engineering was recommended as an approach to teaching students engineering design and the ability to analyze how products are designed and created. The process also helps students to understand optimization, trade-offs of materials, cost, and includes other mathematical and science concepts. If the students are divided into groups for the project, they experience the necessity of good collaborative skills (Childress & Rhodes, 2006).

Reverse Engineering Projects at the College Level

Reverse engineering tasks have been used for years in freshman level engineering design courses at several universities, including MIT, University of Texas in Austin, and the United States Air Force Academy (Wood, Jensen, Bezdek, & Otto, 2001). These disassemble/analyze/assemble (DAA) activities involve projects where students analyze the workings of a product, slowly and carefully dissect the product to examine the mechanical parts and systems and systematically determine how the system works or could be improved. Many college engineering departments have introduced reverse engineering into their curriculum because they saw a need for students to have a more incremental concrete experience with engineering. This process also provides good spatial training for students, which is also important in engineering design (Bar, Schmidt, Krueger, & Twu, 2000). In most cases students are required to work in groups to produce their own reverse engineering project (Wood et al., 2001).

Engineering students who have participated in DAA laboratory activities stated that hands-on experiences helped them to understand the material covered in the class. These activities gave them a chance to probe the mechanical working and systems of the object, while having a fun and motivating experience (Beaudoin and Ollis, 1995; Sheppard, 1992; Wood et al., 2001). Female engineering students noted that the course style helped them to understand the course material better and also increased their desire to become engineers (Beaudoin & Ollis, 1995). Ogot, Okudan, Simpson, and Lamancusa, (2008) noted that "dissection exercises have also been employed in 1 - year introductory courses to provide hands-on experiences for female students to help overcome their anxiety about, and intimidation with, the use of mechanical and electrical devices" (p. 125). When a DAA laboratory class included both traditional methods of presenting the design material and the DAA tasks presenting the material, the mean scores for learning, enjoyment and helpfulness were all statistically significant with students preferring the DAA method (Dalrymple et al., 2011).

Wood, Jensen, Bezdek and Otto (2001) describe the redesign of the freshman level course teaching introductory design at the University of Texas in Austin, the United States Air Force Academy and Massachusetts Institute of Technology. The course incorporates a project using reverse engineering to teach product design. The authors of the paper describe how the introduction of reverse engineering of a product in small teams with specific guidelines and accompanying assignments has improved the course. Through course evaluations and interviews of instructors, the authors feel that students leave the course more motivated to continue in the field of engineering, as well as gaining valuable experience in knowledge in the introduction into the skills needed for engineering design.

Even though DAA projects have been used successfully for many years in first year engineering courses at many top colleges there are few research studies published in peer reviewed journals analyzing their effects on students. Most of the existing literature related to DAA and reverse engineering projects have been presentations at conferences (Lamancusa, Jorgensen, Kumar, & Torres, 1996; McLaren & Jenkins, 2010; Sheppard, 1992) or articles that describe and highlight the information taught within the engineering design course (Barr, Schmidt, Krueger, & Twu, 2000; Wood, Jensen, Bezdek, & Otto, 2001). However, these activities have remained a part of engineering design classes at many universities for the last two decades (Simpson, Okudan, Ashour, & Lewis, 2011).

Iowa State University has included product dissection as a part of their freshman engineering design class since the latter part of the 1990's (Mickelson, Bern, & Freeman, 2000). The university has considered the product dissection to be such a successful teaching tool, that they used product dissection in their weeklong summer engineering camps for rising high school seniors. The feedback from students was positive and students found the experience valuable. The university also offered the reverse engineering opportunities for junior high students who visited the college of engineering (Mickelson et al., 2000).

Even though DAA and reverse engineering have been used successfully at the college level for many years, high schools have been slower to adopt this educational tool. Now that engineering education has emerged as an important curricular addition to K-12 schools regardless of career interests, the inclusion of DAA projects would be a great addition. Exploratory research needs to be conducted on the addition of DAA projects at the high school level and whether it has a positive affect on students' science/engineering self-efficacy and interest, especially with the female students.

Summary

Key to Social Cognitive Theory (SCT) is human agency, the ability of the learner to proactively regulate their own learning through forethought and direct control over what and how they learn (Bandura, 2001). This includes self-efficacy, which is a person's judgement about their abilities to perform specific tasks within a specific domain, and these beliefs can be even more powerful than the actual skill of a performance (Pajares, 1997). Research questions of this study focus on science/engineering self-efficacy and interest. Science achievement and academic performance are correlated to self-efficacy, according to motivational researchers (Pajares, 1995). Authentic learning experiences where students have opportunities to master specific academic skills are considered the component of learning that has the greatest impact on self-efficacy (Bandura, 1997).

Other key concepts of SCT include observational learning and outcome expectations. Students learn by both participating in learning activities as well as by observing others (Schunk & Zimmerman, 1997). Female scientists, engineers and other role models are important motivators as girls consider register for more challenging STEM classes (Britner & Pajares, 2006). When students perceive a positive outcome with their participation in an activity or classwork, they are more likely to pursue further knowledge and in turn, show and increase in subject matter interest (Bandura, 1997).

SCT researchers have primarily used quantitative methodology for their research and often rely on self-efficacy surveys (Usher, 2009). Quantitative studies have shown that males in general have a higher mathematics and science self-efficacy than females (Pajares, 1997, Louis & Mistele, 2012), and even when girls study engineering at elite universities, the girls still have a lower assessment of their mathematics capabilities (Cech et al., 2001) The qualitative SCT research has primarily been at the college level with pre-service teachers, yet qualitative research is needed during the middle school and high school years to provide a richer understanding of self-efficacy beliefs and their origins (Usher & Pajares, 2008).

Researchers have shown other contributing factors to lower representation of females in certain STEM careers. Spatial skills have been shown to be critical in several

STEM fields like engineering and computer programming (Wai et al, 2009) and the American Society for Engineering Education considers spatial skills to be an essential engineering skill (Barr, 2004). Boys have consistently outscored girls on mental rotation skills, as seen by their scores on the PSVT:R (Guay, 1976). However, several research studies have shown that spatial skills can be improved through various training experiences and exercises (Feng et al., 2002; His et al, 1997; Sorby, 2012).

Regarding female interest in STEM fields, Sadler et al. (2012) noted that the most dominant indication of a female student having interest in STEM fields at the end of high school is their interest in a STEM field at the beginning of high school. Interest and goals, according to SCT, are a combination of outcome expectations and self-efficacy (Bandura, 1997).

Engineering education has been added to the Next Generation Science Standards (NGSS, Lead States, 2013). *Encouraging Girls in Math and Science* (NCER, 2007) provided research-based recommendations, which included girls being exposed to spatial activities and providing students with a learning environment that encourages creativity and curiosity. Similarly, other research studies concluded that students desire STEM lessons to be physically and visually engaging (Rowan-Kenyon, Swan, & Creager, 2012) and middle school girls expressed a desire to "learn for themselves" and "figure things out" (Baker & Leary, 1995). To implement these key educational components at the K-12 level, researchers have proposed that engineering education (Dennis et al., 2019; Lawrence & Mancuso, 2012; Moore et al., 2014).

Universities have successfully used Disassemble/Analyze/Assemble (DAA) projects to teach engineering design at the freshman and sophomore levels for the last twenty years (Booker, 2011; Lamancusa et al., 1996; Wood et al., 2001). These hands-on DAA projects have been shown to increase retention of mechanical and technical learning objectives and increase motivation (Calson et al., 1997) and allows for spatial skills training (Barr et al., 2000). Even though engineering education is being implemented at middle and high schools, these DAA projects have not been researched at the high school level. This study investigated the use of a DAA hands-on engineering project at the high school level. The research is designed to examine if and how this project affects female students' science/engineering self-efficacy, interest and career considerations.

Chapter III: Methodology

The purpose of this study is to investigate the use of an engineering education tool called Disassemble/Analyze/Assemble in the high school classroom. The focus of the study is the affect this unit has on the female students who attend a technology academy as part of their high school curriculum. Social Cognitive Theory is emphasized as female students' self-efficacy and interest are explored. The research will seek to investigate the following questions:

1. How and in what ways does the exposure to engineering skills through a Disassemble/Assess/Assemble (DAA) hands-on engineering unit impact high school girls' science/engineering self-efficacy and interest?
2. How does an engineering DAA hands-on engineering unit affect high school girls' consideration of a career in either science or engineering?
3. How does the impact of being exposed to engineering skills through a DAA hands-on engineering differ among female high school students whose scores on the Purdue Spatial Visual Test are either above average, average or below average?
4. Do female students who have elected to take computer courses in high school show differences in spatial rotation skills on the Purdue Spatial Visualization Test (PSVT:R, Guay, 1976; Yoon, 2011) as compared their male counterparts?

Research Design

For this study, I used the research paradigm commonly referred to as mixed methods in order to investigate the use of a Disassemble/Analyze/Assemble unit at the high school level. I collected both quantitative and qualitative data to allow for a deeper understanding of a select group of female students' experiences with this hands-on engineering education project and its effect on their self-efficacy, interest, and career considerations. I used the quantitative data to choose nine female students for the interviews by the process known as stratified purposeful sampling. I collected qualitative data on these female students using semi-structured interviews before and after the DAA project. Social Cognitive Theory provided the theoretical framework for this study and the qualitative data was analyzed using an a priori directed approach to content analysis described by Hseih and Shannon (2005).

Historically, most self-efficacy research in academics has been quantitative in nature (Louis & Mistell, 2012; Multon, Brown & Lent, 1991; Pajares, 1997; Schunk, 1991) and an extensive library of surveys were developed to measure content specific self-efficacy quantitatively (Betz & Hacket, 1983; Kranzler & Pajares, 1997; Lent, Lopez, Brown, & Gore Jr., 1996; Zajacova, Lynch, & Espenshade, 2005). However, there are relatively few published qualitative K-12 self-efficacy research studies related to STEM education (Usher, 2009; Zeldin & Pajares, 2000; Zeldin, Britner, & Pajares, 2007) and there are only a couple of mixed methods primary school science self-efficacy studies (Rich, Jones, & Belikov, 2017; Webb-Williams, 2018). Most mixed methods and qualitative research into self-efficacy involve pre-service teachers or college age students (Usher, 2009).

More mixed methods and qualitative research studies are needed regarding STEM self-efficacy as well as into the role engineering education plays in STEM self-efficacy. These studies can help enlighten different processes students use to judge their STEM experiences and the different junctures in their schooling that are transformative to their self-efficacy beliefs (Usher, 2009). “Qualitative investigations hold great promise for providing a rich understanding of the genesis of students’ self-efficacy beliefs” (Usher & Pajares, 2008, p. 784). Other reasons that I decided that a mixed methods approach was preferred for this study include its usefulness as a method for testing the reliability of a new educational intervention such as the DAA project at the high school level (Collins, Onwuegbuzie & Sutton, 2006), as well as it being the best tool to answer this study’s research questions (Johnson & Onwuegbuzie, 2004).

There are various classifications of mixed methods research depending on the sequence of data collection, the balance in emphasis on qualitative versus quantitative data, whether the study is exploratory or explanatory in nature and the role of theory in data interpretation (Teddlie & Yu, 2007). Clark and Creswell (2008), a well-known mixed methods proponent, developed six commonly used research designs based on these criteria, but other templates have been proposed by various researchers to meet the need for a broader range of designs (Tashakkori, Teddlie & Teddlie, 1998). The mixed methods design that I used for this study is the sequential exploratory mixed methods design described by Tashakkori et al. (1998). The design was sequential in nature since I initially obtained quantitative data. I administered the Purdue Spatial Visualization Test (PSVT:R, Guay, 1976; Yoon, 2011) to students in 5 classes in the Academy of Technology in a high school to investigate the research question of whether any statistical differences existed between the male and female students who chose to attend the technical/computer academy.

I used quantitative data for purposeful sampling in this this study. Purposeful sampling is a widely used sampling technique in qualitative research and is used to identify those participants who are knowledgeable, can provide information about the phenomenon being studied and are willing to share their experiences (Palinkas et al., 2013). Even though randomized sampling is the preferred method of sampling for generalizability, non-probability sampling is a credible method for a labor-intensive exploratory study with a smaller sample size and contributes to internal validity (Bernard, 2006). This technique divides participants into strata from which a smaller sample representative of each level will be chosen to study in more detail (Teddlie & Yu, 2007). Stratified sampling is used to achieve representation or comparability and generate a sample where focus on the depth of the information can address the research questions (Teddlie & Yu, 2007). I used the Purdue Spatial Visualization Test: Rotation (PSVT:R, Guay, 1976; Yoon, 2011) scores from the female students in order to correctly divide students into three spatial ability groups in order to ensure adequate representation.

The remainder of the study's research methodology relied on qualitative data collection and analysis. Engineering DAA projects have not been researched at the high school level and therefore require exploration and depth of study to determine benefits and recommendations. I believe that qualitative data provides a richer data source with the potential for much thicker exploration and descriptions (Bogdan & Biklen, 1997). The research questions are concerned with meanings and reasons, which are better answered through interviews and qualitative data analysis (Bernard, 2006).

One main purpose of this study was to determine the effects, if any, of a Disassemble/Analyze/Assemble (DAA) project on the science and engineering interest, self-efficacy, and career aspirations of high school girls. Another purpose was to expose girls to engineering skills through the DAA project and then determine whether these experiences differed depending on the students' spatial abilities groupings. I obtained qualitative data through two semi-structured interviews, one before and the other after the implementation of the DAA unit. All data was recorded, transcribed and safely secured for privacy. Data was analyzed through direct content analysis (Hseih & Shannon, 2005), in which I used a deductive, a priori thematic approach with themes produced from Social Cognitive Theory (Teddlie & Tashakkori, 2009).

Participants

The sample was drawn from a high school in a midsize Southeastern town that opened in 2017. The school is divided into different academies, and students for this study attended the Academy of Technology, where they study either software development or game design. In a press release for a local newspaper, this school was described as a new kind of educational experience with small learning communities and a unique partnership between the high school students, families, educators and businesses.

Participants were recruited through the Academy of Technology Classes with a total of 124 students either attending the Introduction to Programming classes (2), the Computational Thinking classes (3). There was a total of 105 students in grades 10 and 11, and another 19 students who were seniors. Of the 124 students, 27 were female, 96 were male, one was transgender and 67 were of a minority background. I explained the research to each of the classes, that participation was on a volunteer basis and that in no way would affect the grade in their classes. I sent consent the forms home with the students for parental signatures and explained the assent forms to the students.

There was a total of 94 students who took the PSVT:R (Guay, 1976; Yoon, 2011) test, with 71 male, 22 female and one transgender students. Of the 22 female students, 13 returned their parental permission forms to allow their PSVT:R score to be used in the study and 11 returned signed parental permission forms to allow interviews for the study. One transgender student returned her parental permission forms for both the interviews and the PSVT:R scores to be used in the study. Of the eleven female students, 9 where chosen for interviews by purposeful stratified sampling so that above average, average and below average scoring students on the PSVT:R were equally represented. Two of the nine students were African American, one was Hispanic, and one was Asian. The others were Caucasian. A transgender student also participated in the interviews and was Caucasian.

Instructional Unit

Day 1. The Disassemble/Analyze/Assemble (DAA) hands-on engineering unit introduced students to various engineering skills over the period of two, hour and a half class periods. There was a total of 128 students in 5 class periods who participated. On the first day, students disassembled a computer, naming various components and their purposes (power supply, RAM, hard drive, CPU, etc). Computers were either donated by individuals or obtained from a computer recycle company. Privacy was maintained with computer hard drives, computers were not turned on, and students were not allowed to take home computers or components. Students were given the required tools and static bracelets needed to complete the task and the classroom instructor and I gave a presentation describing important computer components and necessary steps to safely take the computer apart prior to any disassembly. Students were given instructions to either take photographs at each point during the disassembly, or to document the process with paper and pencil. Students were given plastic containers for small components and parts as well as the necessary tools for disassembly. Then students worked in groups of 2 to 4 to remove various components from their computers, document their work and identify these components and their purposes. The classroom teacher and I walked around the classroom encouraging students, giving students instructions when needed, and asking students to identify key components of the computer. Afterwards, students reassembled their computers, ensuring that all the parts were installed correctly.

At the end of class periods, students were given a short spatial skills lesson on orthographic drawings with a worksheet to be completed in class. The lesson taught students how to produce and interpret orthographic drawings of 3-D objects and how these drawings are used by engineers, architects and machinists. Students were given interlocking cubes purchased from Amazon and worksheets from Teach Engineering: STEM curriculum for K-12 website sponsored by the University of Colorado, Boulder. This assignment allowed students a visual and hands on illustration of orthographic drawings as they completed assignments. I have included the worksheets in the Appendix.

Day 2. On the second day, I taught a short lesson on basic electrical circuits and the difference between parallel and series circuits. I gave the students handouts of drawings I made of the series and parallel circuits that were present in the LED flashlight which I have included in the Appendix. Then I gave a PowerPoint presentation photographs that I had taken while disassembling the fan and LED light at home. The photographs modeled the process of disassembling both products, and I warned that the wires were easy to disconnect if not careful. Students were given needed supplies, tools and containers for the DAA process. Students were divided into groups with 4 to 6 students at each table, where half of the students would disassemble, analyze and reassemble a handheld fan and the other students would do the same for a small LED flashlight. During this time, the classroom teacher and I circulated among the different groups, encouraging students, discussing the mechanical and electrical processes, as well as discuss production materials (metals, plastics) and possible production constraints. Once students correctly reassembled their item, they would move to disassembling the other product.

Role of the Researcher.

Different from the consistency in quantitative research, qualitative researchers in the behavioral or social sciences are human beings investigating other human beings. The interactions between the interviewer and the study participants are filled with unique responses as with any other relationship (Schreier, 2012). Within Social Cognitive Theory, Bandura (1986) describes the acquisition of knowledge as an interconnected process which he called triad reciprocal causation. This includes the interplay between personal, environmental and behavior factors (Bandura, 1986). The role of the relationship between the researcher and each of the participants in the interviews is dynamic, each learning and responding to the other.

Data Collection

Phase One – Spatial Skills Test

The first phase of the research study was quantitative in nature, using the PSVT:R (Guay, 1976; Yoon, 2011) for stratified purposeful sampling. This test was designed in 1980 and is used to measure 3-D mental rotation ability for persons age 13 and above. It contains 30 multiple choice questions involving mental rotation of 13 symmetrical objects and 17 asymmetrical objects (Guay, 1976). The test was revised by Yoon (2011) with Guay's permission to eliminate several small errors. In a meta-analysis of gender differences in spatial abilities, Madea and Yoon (2012) note that Cronbach's alpha reliability coefficient was between 0.80 and 0.86, which indicates a high level of reliability. Maeda, Yoon, Kim-Kang, and Imbrie (2013) published a study on the psychometric properties of the revised PSVT:R with first year engineering students and stated that both exploratory and confirmatory factor analysis showed a single factor model, indicating that measurement of the 3-D mental rotation spatial ability construct. I chose to use this test due to its reliability and validity as well as its measurement of skills that have been shown to be useful in several STEM careers (Wai et al., 2009). Also, the mental rotation skills used when taking the PSVT:R have been shown to have consistent gender differences with male students outperforming female students (Linn & Peterson, 1985; Voyer, Voyer, & Bryden, 1995).

I submitted the Institutional Review Board (IRB) forms at the University of Kentucky and followed their safety protocols for work with human subjects and children. After receiving approval from UK IRB, I obtained permission from the public school's central office. I also obtained permissions from the high school's principal, the head of the Academy of Technology and the teacher of the classes I used for the sample's study.

After the IRB approval and the needed school permissions, I obtained informed consent from the participants' parents and adolescent assent forms from the participants prior to any data being collected. The informed parental consent forms were separated into two different forms, one for the PSVT:R (Guay, 1976; Yoon, 2011) test and the other for the interviews to be obtained before and after the DAA unit. These permission forms which UK IRB had reviewed were sent home with the students for their parents read and sign. There were also two student assent forms for the PSVT:R (Guay, 1976; Yoon, 2011) test and the interviews. I gave students an explanation of both parts of the research and explained that participation was completely voluntary. Students participated in the DAA project regardless of whether they participated in the research since it was a part of their classroom schedule. Students were also told that if they chose not to be a part of the research, it would not affect their grade for the course.

I administered the revised PSVT:R (Guay, 1976; Yoon, 2011) as a PDF file on the computer to every student present on test day in the five classes and answers were written on scantron sheets, which I graded manually. However, I only used the data from those who provided me with signed parental permission forms and signed assent forms. I used the quantitative data to answer two research questions. The first is how does the impact of being exposed to engineering skills through a DAA hands-on engineering unit differ among female high school students whose scores on the Purdue Spatial Visual Test are either above average, average or below average? The second question wonders if female students who have elected to take computer courses in high school show differences in spatial rotation skills on the PSVT:R test as compared their male counterparts? The other use of the PSVT:R test was for purposeful stratified sampling to determine which students would participate in interviews.

The mean score for the 13 female students who took the PSVT:R in the Academy of Technology was 16.46. However, when I analyzed only the 11 students who obtained signatures on the parental permission forms allowing for interviews, the mean was 16.73 I decided to use the scores only from students who chose to allow interviews when determining the three grouping to ensure adequate representation from throughout the range of scores. Above average scores were grouped 22 to 30, Average was grouped 15-21 and below average scores were 0 to 14. With this division, I chose three female students from each of those score ranges for a total of nine students for the interviews.

Table 3.1

Purdue Spatial Visualization Test: Rotations (PSVT:R) Female Scores

Student	**PSVT:R Score**	**Interviewed**
	Above Average	
Chloe	25	Yes
Gabriella	25	Yes
Hailey	24	Yes
Samantha*	20	No
	Average	
Sophie	17	Yes
Taylor	17	Yes
Kayla	16	Yes
Lily	16	No
	Below Average	
Naomi	13	No
Jordan	12	Yes
Hannah	11	Yes
Emily*	9	No
Alexis	3	Yes

*Parents gave permission for students' PSVT:R (Guay, 1976; Yoon, 2011) score to be used in research, but not interviews.

Table 3.2

Purdue Spatial Visualization Test: Rotations (PSVT:R) Male Scores

Male Students	**PSVT:R Score**
Liam	28
Justin	26
Noah	24
Gabriel	18
Tyler	18
Isaiah	13
Lucas	13
William	12
Oliver	11
Ben	10
Brandon	7
Caleb	5

Phase Two and Four – Interviews

I chose to interview participants in person rather than to use surveys since this study is exploratory in nature and the interviews allowed for further clarification, probing and depth into the use of DAA at the high school level (Teddlie & Yu, 2007). I interviewed each participant twice. Once was before the DAA unit, in order to obtain background information regarding the participants' science and engineering self-efficacy beliefs and experiences, future course selections, and their role models. The second interview occurred after the unit, to discuss the unit and any impacts it may have had on the students. Since this project is also exploratory, I also asked students about possible changes or additions to the project they might make.

The first interviews were semi-structured and were conducted for each of the nine students in the week or two preceding the DAA activities. Both sets of interviews were conducted in the school library during the students' technology class periods, in a separate room for privacy. All interviews were audio recorded only on a Zoom handy video recorder Q3 and were transcribed by me. I used semi-structured in person interviews because it allowed me a chance to clarify any questions and have personal interactions with the students (Bernard, 2006). The interview questions were open ended to encourage students to express their own thoughts and experiences in detail and from their own frame of reference (Bogdan & Biklen, 1997). The first set of interviews lasted between 30 and 45 minutes, in order to ensure thoroughness. I used interview guides for both interviews, which I have included as Appendix A and Appendix B, because it can allow qualitative data to be more reliable and comparable (Bernard, 2006).

The questions and topics in the interviews were developed using Social Cognitive Theory, as well as topics covered by other qualitative self-efficacy researchers (Usher, 2009). Questions for interview protocol 1 were developed using key concepts from SCT which focused on the development of self-efficacy beliefs through experiences at home and school. Questions discussed varying methods students used to self-regulate their learning, observational learning experiences and their STEM interest. Other questions were developed to gain information about students' career aspirations, role models and experiences that motivated their learning. The questions for interview protocol 2 focused on students' learning experiences with the DAA unit. Other questions also related to their curiosity and interests, and the pursuit of knowledge in their leisure time.

After the DAA unit was completed, I interviewed the participants for the second time. The format was also semi-structured with an interview guide, mainly discussing with the students their experiences with the DAA set of lessons. These interviews also occurred in the school library and lasted approximately a half hour. The interview questions focused on their self-efficacy experience and science and engineering interest related to the DAA project. Semi-structured interviews are used in qualitative research to contextualize an intervention (Creswell & Tashakkori, 2007). Prior to these interviews, I also reviewed the previous interviews to determine if there are questions that need further clarification or had been omitted from the first interview.

I audiotaped these interviews with permission from parents and assent from the participants. I jotted down notes during the interview for items that cannot be easily ascertained from the audio tapes. Bernard (2006) recommends that all semi-structured interviews should be audio taped and notes should be taken during interviews to capture non-verbal cues and expressions. In order to record the most possible data and assure the reliability of the observations, field notes and observational notes must be completed as soon as possible after the field experience (LaCompte & Schensul, 2010). These recorded interviews will be kept safely locked in a container and will remain locked securely in the container while the equipment is at school and within my home when school is not in session. Interviews were transcribed by me to Microsoft Word along with the notes taken during each interview. Notes taken during interview were transcribed into Microsoft Word during the day that the interview occurred. For security and privacy, the transcribed notes are on a computer that is password protected.

Phase Three – DAA Instructional Unit

Table 3.3

Overview of Instructional Unit

Day	**Overview of Lessons**
1	Lesson about key computer components and the process of disassembling a computer. Students worked on computers in groups of two to four. They documented their work with photographs or drawings Students identified key components of the computer and their purposes to classroom teacher and researcher. Spatial lesson given using orthographic drawings and interlocking cubes (see Appendix C).
2	Lesson about motors and electrical circuits. Presentation given to students with process and pictures of taking apart the handheld fan and the LED light. Students were divided into groups of two, with one student disassembling and analyzing a handheld fan and the other the LED light. Students documented work, discussed mechanical and electrical processes with instructors, and reassemble both products to working order (see Appendix D)

Data Analysis

The qualitative data collected in this study was analyzed using an a priori directed approach to content analysis described by Hseih and Shannon (2005). Content analysis is defined as, “A research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns” (Hseih & Shannon, 2005, p. 1278). Direct content analysis is commonly used when there is a substantial body of theory in place and codes can be predetermined or used as the basis of coding (Hseih &Shannon, 2005). This use of prior research has also been referred to as the deductive role in content analysis (Potter & Levine-Donnerstein, 1999). However, the approach is flexible and when data occurs that does not fit into an existing code, new codes or subcategories of codes can be used (Hseih & Shannon, 2005). This qualitative portion of this study is exploratory in nature using the understanding of the acquisition of knowledge based on Social Cognitive Theory. The coding manual initially contained key concepts based on Social Cognitive Theory with an extension of additional codes that were added for key concepts of interviews that did not fit well in the existing initial coding options or were subcategories of the coding options.

According to Mayring (2004), the process of formative checks throughout the coding process rather than just a summative check at the end is essential for reliability. Another important consideration when performing deductive or directed content analysis is the need for explicit definitions of categories and specific coding rules with examples. The codebook should prescribe the circumstances when specified codes are to be used (Mayring, 2004). “In content analysis, reproducibility is arguably the most important interpretation of reliability (Krippendorff, 2004, p. 215).

I transcribed the interviews myself and was able to contemplate themes during this process. Then on my first read of the transcribed interviews, I highlighted key words and phrases related to STEM self-efficacy components, science and engineering interest, experiences, and career considerations and items that affected these for students. The unit of analysis were not words, but phrases, sentences or paragraphs that contained Social Cognitive Themes. This process occurred without initially coding the material in order to allow me to initially capture the important information in context without making judgements on specific decisions on coding categories. I then coded all highlighted passages using predetermined codes initially generated from Social Cognitive Theory such as self efficacy sources, mastery of tasks, observational learning, science and engineering interest and career considerations which were contained in a coding manual with definitions. Any of the highlighted text that did not fit into the existing codes were given new codes and included in the coding manual.

I entered all the transcriptions into NVivo 12 in order to organize and further analyze the qualitative data (Hsieh & Shannon, 2005). Qualitative software packages can be useful for data management, multiple coding locations for the same passage, and retrieval of data for each individual code (Schreier, 2012). I proceeded to review the transcripts a fourth time and categorize the themes into nodes in order to determine the consistency of the coding and whether any relevant information had been omitted. This software package allowed sections to be coded in more than one node. I reviewed each node, such as mastery experiences, and determined if the node could be divided into subcategories or if new sub-nodes needed to be added due to emerging themes. I reviewed the themes and subthemes with multiple occurrences, concentrating on the affect of the DAA project on these students.

In order to answer the last research question, quantitative data was required. The sample included 13 male students and 13 female students. An independent sample t-test was used to compare the mean PSVT:R (Guay, 1976; Yoon, 2011) scores of male students (*M*=15.15, *SD*=7.809) and female students (*M*=16.46, *SD*=6.591) in the Academy of Technology. SPSS version 26 was used to conduct the statistical calculations. The level of significance was set at 0.05. This question is of interest since the female students applied to attend the Academy and had therefore chosen a technical educational pathway in high school. The number of male samples were also limited due to having difficulty with students returning their parental permission forms for the study. Part of this could be due to the study being performed in April and May and students had many other distractions.

Chapter IV: Analysis

Overview

I begin this section by giving you some background information about each of the nine participants in the study and which spatial ability grouping they inhabit. Table 4.1 presents the thirteen girls using pseudonyms who allowed their PSVT:R (Guay, 1976; Yoon, 2011) scores to be used for this study and the eleven girls who were willing to be interviewed. Then I present the analysis of the qualitative data, divided into various Social Cognitive Themes and spatial groups to answer the research questions of this study. Lastly, I present the quantitative data from the PSVT:R.

Table 4.1

Student PSTV:R Scores and Demographics

Student	PSVT:R score	Race**	Class	Interviewed
	Above Average			
Chloe	25	C	11	Yes
Gabriella	25	C	11	Yes
Hailey	24	AA	10	Yes
Samantha*	20	Asian	12	No
	Average			
Sophie	17	AA	10	Yes
Taylor	17	C	10	Yes
Kayla	16	C	10	Yes
Lily	15	C	11	No
	Below Average			
Naomi	13	C	10	No
Jordan	12	C	10	Yes
Hannah	11	Asian	12	Yes
Emily*	9	Asian	12	No
Alexis	3	H	11	Yes

*Parents gave permission for students' PSVT:R (Guay, 1976; Yoon, 2011) score to be used, but not interviews.
**C=Caucasian, AA=African American, H=Hispanic

Background of Participants

Above Average Spatial Group

Chloe is a junior who likes art and technology. She considers herself to be more task oriented than people oriented. She is taking AP calculus AB and physics. She is confident in her computer skills, but not confident enough in her math skills to pursue engineering, in her opinion. Her plan for college is to major in web design or graphic design.

Gabriella is a junior and both of her parents are computer programmers. She says that computers and technology have always been a part of her life. She was homeschooled starting in late elementary school, and states that she was already behind in math at that point. She takes Advanced Algebra II this year with mostly freshman and sophomore students but plans on taking statistics her senior year so that she will be with other seniors. She plans to be an oral surgeon ultimately, but first plans to go to college and double major in business and computer science.

Hailey is a sophomore with the unique experience with helping a teacher at her high school repair broken screens on the school's Chromebooks. She took an Introduction to Computer Programming at a different high school last year. Since she enjoyed the class so much, she continues to pursue more classes with computers. She sees herself one day working as a field agent in the FBI, seeing it as a cool job and a way to help people and combine her love of law enforcement and technology.

Average Spatial Group

Sophie is a sophomore who sees knowing technology as something important for her future. She desires to become a veterinarian because she sees it as a career where she can help people and animals at the same time. She had a unique way of describing the job of a scientist as a person who "thinks of ways to preserve life." She prefers geometry to algebra, is taking biology and is also interested in music.

Taylor is a sophomore who enjoys science and learning how things and the body work. She is in geometry and biology and is considering engineering as a college major. Taylor likes working in groups because it inspires her to learn. In describing her ideal job, she states that she sees herself being a smaller part of a bigger project or plan.

Kayla is a sophomore who enjoyed digital literacy in middle school. She enjoys both math and science and describes computers as a good way to integrate those skills. She is in AP biology and geometry and tells me that her math teacher says that she should be in a higher mathematics class. She took a 9-week pre-engineering course in both 7th and 8th grade and enjoyed creating and building. She sees herself majoring in computer science in college.

Below Average Spatial Group

Jordan is a sophomore whose dad is a computer software engineer. She began working with computers through Student Technology Leadership Program (STLP) in 4th grade. Her classes include advanced biology, advanced physics and pre-calculus and plays in the school orchestra. Jordan likes group work in classes and perceives that having different views enables her to be a better person. In her opinion, STEM subjects are her strongest and she desires a college major in the science field. One of the possible majors she is considering is environmental engineering.

Hannah is a senior and remembers going to her uncle's house as he worked on repairing computers and putting together computer components to assemble a new computer for customers. She enjoys art, music and graphic design. She chose to take probability and statistics her senior year because of others complaining about calculus. She also mentions enjoying geometry and physics. She found that putting make-up on actors for a school play was satisfying and said that it made her feel fantastic. She is looking into beauty school for the present and then maybe go to college a few years down the road.

Alexis stated that she was only in Academy of Technology because her counselor thought it was a good idea. She is in Algebra II, really likes the math class and says she is one of the few students willing to answer questions. Due to a family situation, she has changed schools several times in the last few years and she often spends hours outside of school caring for her two young cousins. Alexis likes art, cooking, and plans on taking a digital art class next year at school. She plans on going to community college and studying digital art to become an illustrator or study in the culinary arts.

Qualitative Data Analysis

In analyzing the interview data, several themes emerged and will be discussed in this chapter. To begin with, the Disassemble/Analyze/Assemble (DAA) project and spatial activities provided students with a good hands-on opportunity to improve their science self-efficacy through problem-solving as students struggled through certain tasks, made mistakes and ultimately found success. Students were also able to improve their self-efficacy through connecting previously learned science concepts such as electricity and circuits to their use in everyday products. For students who did not remember or had not recently learned about electricity in science courses, I presented these concepts during an instructional phase prior to the disassembling phase in order to encourage the cognitive connections between these concepts and their uses. Two students specifically mention the sense of accomplishment that came with the project.

There was also evidence that for some students, their science and engineering interest also increased. This was demonstrated by the combination of the hands-on mastery experiences through problem solving, cognitive connections students made to science concepts and the positive learning experiences students expressed during interviews. To clarify whether the quotes occurred in the first interview, which occurred before the DAA unit, or the second interview, which occurred after the DAA unit, I have included after each quote the words “pre-DAA unit” or “post-DAA unit”.

Self-Efficacy Mastery Component – Problem Solving and Science Connections

Students were given various opportunities to problem solve during the DAA project. In order to determine if the handheld fan and the LED flashlight were reassembled correctly, the items needed to still operate after reassembly. Another one of these problem-solving opportunities related to the switch on the fan. When the fan was disassembled, the switch would easily fall out. Upon reassembly, it needed to be reattached in a very specific way in order to close the electrical circuit (see figure 1). The LED light had a switch that changed the circuit from a larger frontal light to a smaller, less dim, side lights (See figure 2). The configuration of the front light circuitry was in series and the side lights were in parallel. This provided students a great opportunity to connect previously learned science content in electricity to an actual product. The circuitry for the handheld fan was in series.

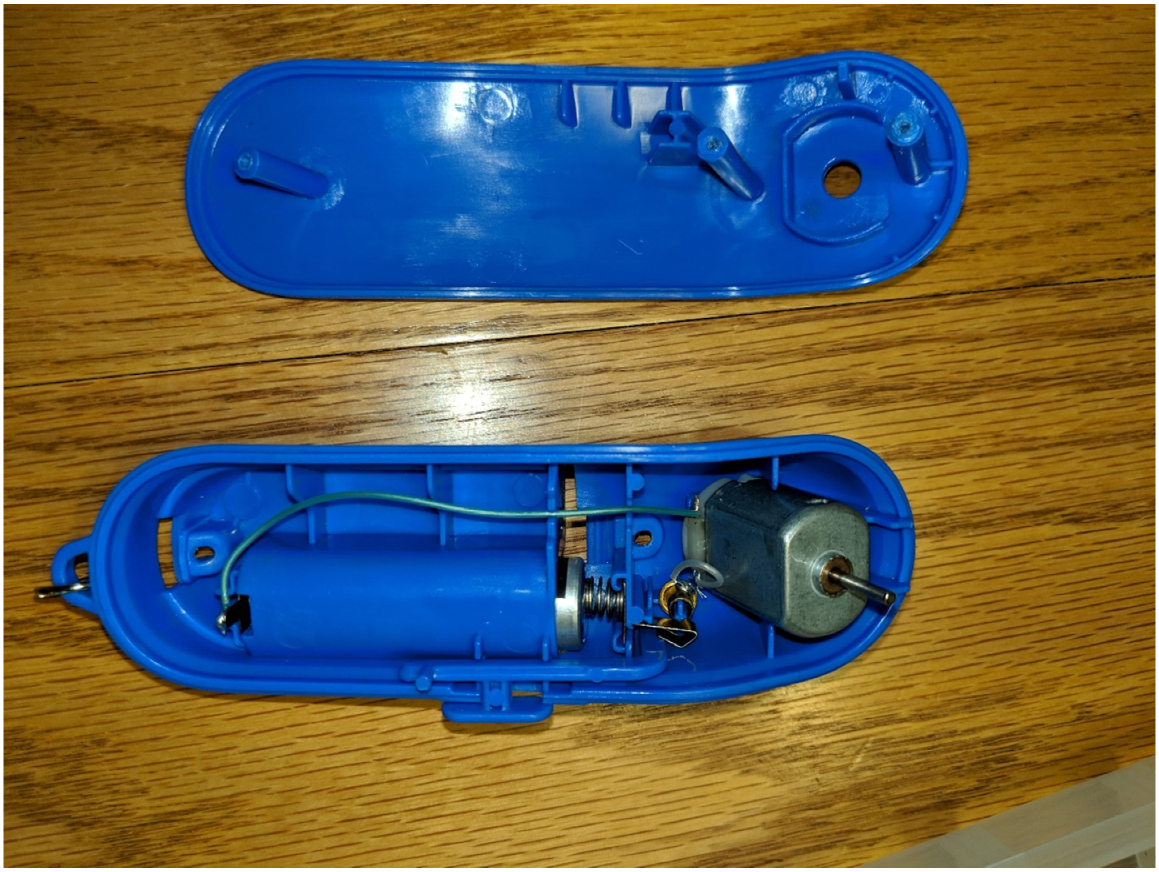


Figure 1: Handheld fan disassembled.

The disassembly and assembly of the desktop computer towers presented more problem-solving opportunities for students (see figure 3). Even though the classroom teacher and I explained some basic techniques for disassembling the computer, the process still required more complicated problem-solving and spatial awareness than the fan or the LED flashlight. Six of the students also commented specifically upon the connections they were able to make between science classes and the inner workings of these products.

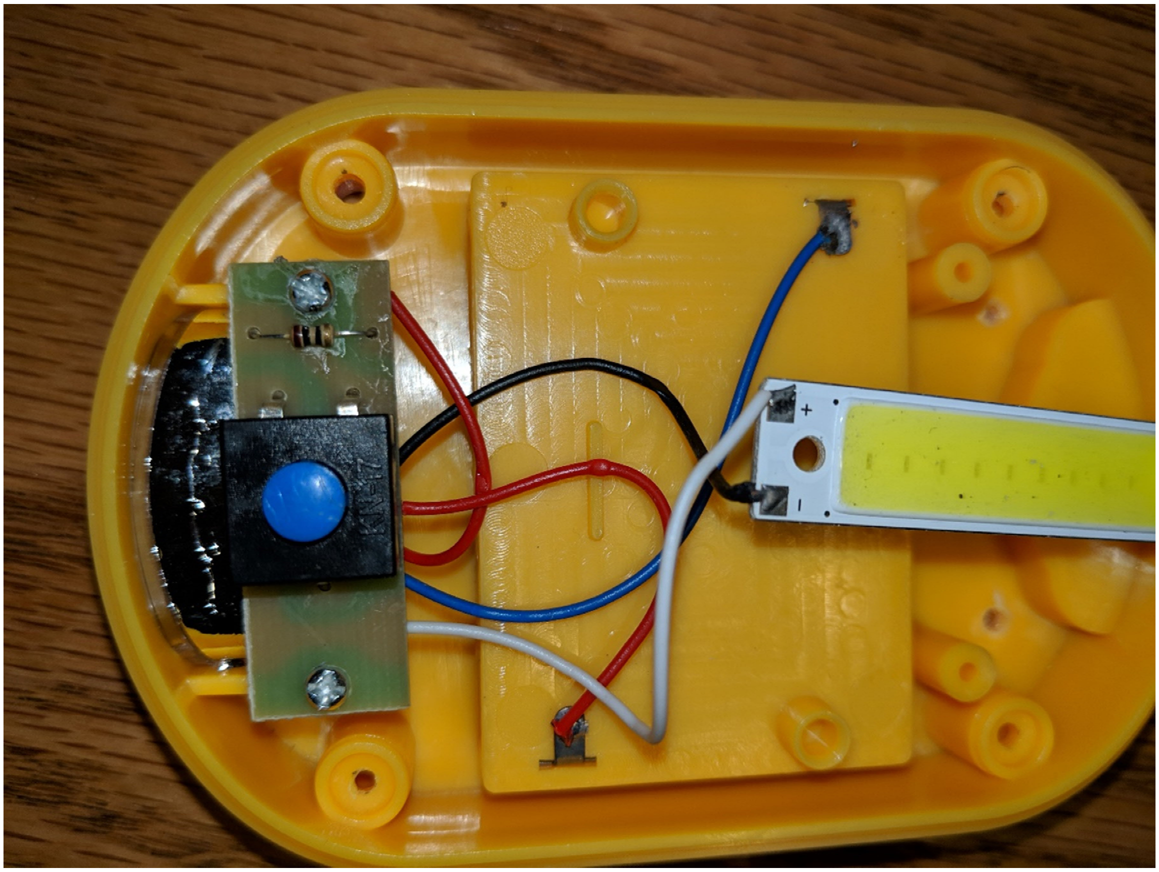


Figure 2. LED flashlight disassembled

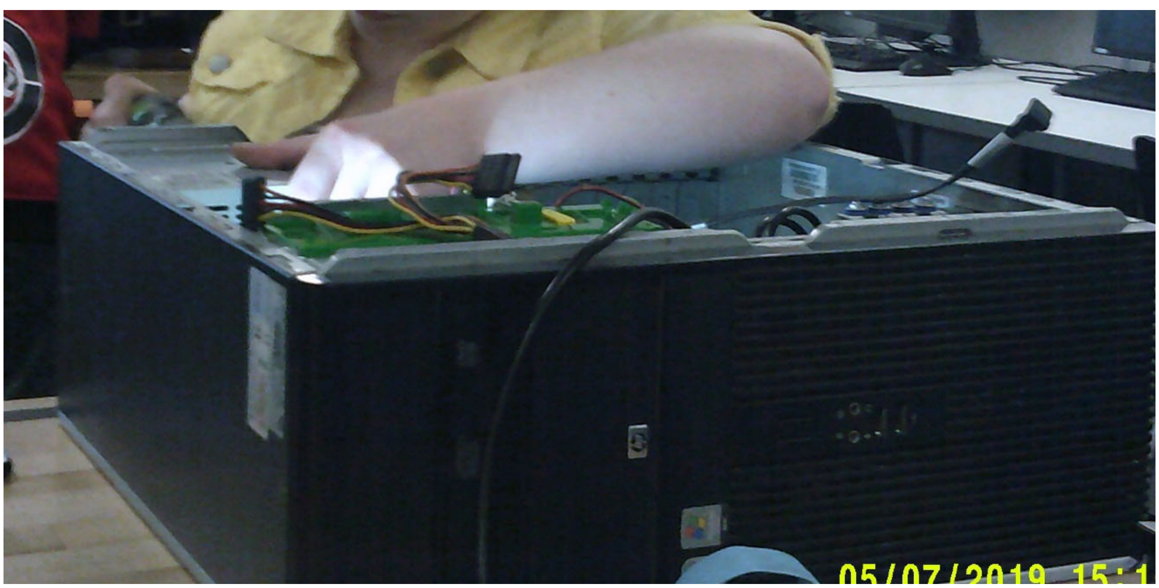


Figure 3. Partially disassembled desktop computer.

Above Average Spatial Group

Chloe explains the connections she was able to make between the DAA fan and LED experience and what she had learned in her physics class.

> Because the day before I had my physics class and we started doing electricity and they had mentioned resistors which was why I was so excited whenever I found that. So it, that was especially interesting taking apart that after having a general, that general look into how circuits are (post-DAA unit).

Referring to the circuitry in the LED flashlight, she also states, "I was curious about seeing how it worked with the parallel circuit and the light how one went to one light and, or one set of lights and then the other section went to the lights on the side (post-DAA unit)." Hailey describes her feelings and says, "It feels pretty good. Yeah it is a good sense of accomplishment, because it is like, oh that's cool, it works again. Like I just did that (post-DAA unit)."

Average Spatial Group

Sophie explained her DAA experience and how it was an experience in problem-solving.

> How you have to put certain things in there in a certain way for it to work, to all fit in that one area…you have to remember how it was and try to figure out how to put it back how it was. So I would like put something in there and have to take it back out. It was fun to figure out what parts were what. My favorite part was putting it back together and making sure it still worked (post-DAA).

Kayla mentions that, "In science classes we've learned about electricity and the way that works, but we've never been hands on with something like that (post-DAA)." Taylor was also taking physics and she states,

> Then we talked about all the resistance and that stuff and I was like, and now we walk into here and we are talking about circuits and I'm like oh, I just learned about this 10 min ago. Let's do it (post-DAA unit).

Sophie talked about the sense of accomplishment that she felt through this project.

> Well at first, I was like, this could be very difficult for me, because I break things a lot. I was like, oh man, I don't want to get in trouble, but then I started doing it, and I was like, this is pretty fun. I stopped thinking negatively about it and thought this will be fun. And I started doing it, and I was like, I'm fine, I'm fine and it was fun. I have never done anything like that before and it was a fun time (post-DAA unit).

Below Average Spatial Group

When Jordan talked about her experience with the DAA process on the computer she noted, "It was challenging because all of the wires, you had to take pictures and recognize where the wires went and which ports they plugged into (post-DAA unit)." Jordan also mentioned the switch on the handheld fan and stated,

> and you had, like a power button you had to make sure when it went in it was touching a piece of metal that connected to another piece of metal and it ran it. So that was, that was a little hard… you had to make sure, when it went it was touching a piece of metal that connected to another piece of metal and it ran then (post-DAA unit).

Hannah describes her problem-solving experience with, "the switch sometimes you like accidently popped the switch off, you had to figure out how to put it back together (post-DAA unit)."

Students' Spatial Experiences

Spatial reasoning was an important tool used by students to be able to problem solve during the DAA project. To encourage spatial reasoning, I presented students with a spatial activity using plastic cubes and orthostatic drawings. Orthostatic drawings are used by engineers and architects to represent a three-dimensional object on a blueprint by using the object's top view, side view and front view projections. Even though this was a relatively short activity, students practiced using orthographic drawings to build simple figures using interlocking cubes. Worksheets were obtained online from Teach Engineering: STEM curriculum for K-12 website sponsored by the University of Colorado, Boulder and are included in the Appendix.

Above Average Spatial Group

When discussing the spatial activity during the interviews with students, Gabriella stated that,

> having the blocks helped a lot cause, like and I know that was the point of the exercise, but I think like if I had done that exercise and then taken the spatial reasoning test, I might have done better (post-DAA experience).

When talking about previous experiences with spatial activities in Chemistry class, Hailey says

> The visual things are harder. The two-dimensional things aren't very, they are not bad. Like I can do those fairly well, but three-dimensional visual understanding is a little harder for me to picture in my head, especially with all the molecules and where they attach (pre-DAA unit).

Average Spatial Group

When speaking about her experience with the taking the PSVT:R spatial test (Guay, 1976; Yoon, 2011), Kayla stated, “I don’t think you do a lot of those things in other classes where you recognize patterns and something like in motion, so I thought it was pretty interesting (post-DAA unit).”

Below Average Spatial Group

Most of the students said that they did not remember having any spatial activities in any class other than art. Jordan commented that

> It is good to look at things from different angles…It was hard for me to stretch out my mind. There was one that I kind of got tripped up on and had to ask for help, but it was good (post-DAA unit).

Science and Engineering Interest and Enjoyment

Most students expressed that they had enjoyed these hands-on experiences, especially with familiar household items.

Above Average Spatial Group

When Hailey talked about the DAA process, she said, “It feels pretty good. Yeah, it’s a good sense of accomplishment because it is like, oh, that’s cool, it works again. Like I just did that (post-DAA unit).”

Average Spatial Group

When I asked Kayla to describe her thoughts on the DAA experience with the fan and LED flashlight, she comments

> I guess I like kind of learning how everyday items work. That is always something that has been interesting to me, especially like taking apart a fan that

you used to use when you were younger all of the time. And so just like taking it apart and getting really hands on with it was pretty interesting (post-DAA unit).

Below Average Spatial Group

Hannah states that "I really enjoyed taking the computer apart cause it like made me understand it, like what is connected to what. And better understand the pieces and how they work (post-DAA unit)."

Four of the nine students specifically stated that the would be interested in disassembling other similar items in the future.

Previous Disassemble Experiences

When analyzing the affect the DAA project had on students, it is important to know which ones had prior experiences with taking items apart, fixing computers or other similar activities. In this case, five of the nine students did have limited previous experiences and the other four had no experiences.

Above Average Spatial Group

Gabriella had taken apart a printer. Hailey had a unique experience with Chromebooks. "I helped one of the teachers here repair Chromebooks, so I learned how to take the screen off and switch it out for a new one (pre-DAA unit)."

Average Spatial Group

Kayla had disassembled Wii remotes when she was younger but had not fixed them or reassembled them. She did not have any other DAA experiences

Below Average Spatial Group

Jordan explains her previous DAA experience,

> So like you would put a fan into your charge port and it would run off the battery in your charge port and it would run as a fan and I took it apart and I put it back together and it had the same kind of motor in the fan (post-DAA unit).

Career Considerations – Role Models

This study data included insight into various role models for the participants. I asked students if there were any role models that motivated them or had a specific job that looked interesting to them.

Above Average Spatial Group

When I asked Hailey about role models that she has and what interested her in computers, she says,

> one of my cousins, my mom's cousin, she works at the NSA. They recruited her out of high school and she got to do all this cool stuff. They paid for her college education and she works there and I think that is so cool. The other reason is that I actually used to be a huge fan of the TV show Arrow and saw Felicity Smoke on there and I was like, "That's so cool, like I want to be able to do that." So I took a programing class last year. I liked it, so I just kind of kept going (pre-DAA unit).

Hailey also told me that these role models help motivate her and keep her from just settling for mediocre. Chloe described a video game character to me, who is a female but wants to be a detective.

> But in this society that she lives in, that's the traditionally male job and so for a large part of the story she pretends, she like dresses up like a man in order for people to take her more seriously as a detective. But then she finally comes to terms with she doesn't want to be a man, she just wants to be a detective and sort

> of reconciles both of those together and I think that is very, I find that really relatable (pre-DAA unit).

Average Spatial Group

Kayla talked about the show Criminal Minds. “I love their sort of way about going about things. When they are like kind of profiling somebody, because that is sort of what I want to do” she says (pre-DAA unit).

Below Average Spatial Group

However, only some of the students’ role models discussed in the interviews were from a media source. Hannah describes her computer teacher and her decision to take the computer course from him this year.

> I’ve always looked up to him honestly, even though I never really had him as a teacher last year, but I was occasionally in his classes. I thought the stuff they were doing was really cool so I decided to take them my senior year. And I always looked up to him because he was pretty successful with his technology outcome and I thought it was really incredible (pre-DAA unit).

Of the students who discussed the impact of specific role models, four of the nine female students referred to specific media or video game role models. Six of the nine students stated role models included parents, teachers, siblings and other relatives.

Similarities Between Spatial Groups

First, I would like to discuss the similarities the data showed with students of all three spatial groupings. The data showed that the experience of disassembling the computer, identifying various components and their functions and then reconnecting these components had similar effects on students in all three of the spatial groupings. All groupings expressed that the process helped them to understand functions of various components and how these components were connected. All groups expressed an enjoyment of being able to personally participate in this hands-on project and it was evident that it provided good problem-solving experiences for all groups.

The portion of the DAA project with the LED light and the handheld fan also provided students with good problem-solving experiences. Students in all groups made comments about connecting conceptual knowledge they had learned about electricity in previous science classes to the actual circuitry process they were able to see in these products.

Students in all three groups described positive experiences with the spatial lesson involving the orthographic drawings and the interconnecting cubes. They described the experience as useful, challenging and unique in that they had not participated in similar spatial activities in previous classes.

Differences Between Spatial Groups

When I reviewed the data for differences between the three groups, most areas only showed minor differences or differences in degree. The most pronounced difference was that students in the above average group considered the experience with the LED light and fan a little less challenging than members of the other two groups. One person in the above average suggested for the future having an activity that required more challenge and more potential for problem-solving.

The data only showed minor differences between the three groups with respect to the computer experience. Students in all groups found aspects of this activity challenging but the average and below average groups to a greater degree. One student suggested that in the future, it might be helpful to do a DAA activity where the teacher leads the students in an activity together before students attempt an activity independently.

Quantitative Data Analysis

The reason I chose the PSVT:R (Guay, 1976; Yoon, 2011) test of mental rotation spatial abilities was its salient use in educational research and is well studied. The test consists of 30 multiple choice questions, 13 of which are symmetrical three-dimensional objects and 17 non-symmetrical objects. The objects were drawn using isometric format (Maeda & Yoon, 2013).

Using SPSS, I obtained the descriptive statistics on 13 male and 13 female students who took the PSVT:R. The reason for 13 was these were the students who returned their parental permission forms and gave assent.

Table 4.2

Descriptive Statistics for Entire PSVT:R

	N	Min	Max	Mean	SD	Variance
PSVT:R female	13	3	26	16.00	6.532	42.667
PSVT:R male	13	5	28	14.62	7.687	59.090

Using SPSS 26, an independent sample t-test was conducted to compare the PSVT:R (Guay, 1976; Yoon, 2011) scores of male students (M=15.15, SD=7.809) and female (M=16.46, SD=6.591) students in the Academy of Technology. There was not a statistically significant difference in the male and female scores, $t(24)=0.495$, $p=0.625$, despite the female students attaining a higher mean score than the males.

The PSVT:R is a long and difficult test, especially for high school students. For this reason, I also analyzed student scores on specific groupings of questions to determine whether there were any gender differences. Table 4.3 describes the scores for questions 1 through 7. These questions have been isolated because the mental rotation required to answer the questions can be performed in one step (eg. Rotate figure 180 degrees, or flip figure 90 degrees).

Table 4.3

Descriptive Statistics on Male and Female Students for Questions 1 through 7

	N	Min	Max	Mean	SD	Variance
PSVT:R female	13	0	7	5.15	2.035	4.141
PSVT:R male	13	0	7	4.31	2.057	4.231

Using SPSS 26, an independent sample t-test was conducted to compare the PSVT-R scores for questions 1 through 7 of male students (*M*=4.31, *SD*=2.057) and female (*M*=5.15, *SD*=2.035) students in the Academy of Technology. There was not a statistically significant difference in the male and female scores, $t(24)=1.054$, $p=0.302$. Even though there was no statistical difference, the mean difference for questions 1 through 7 showed the greatest percent difference of all the other comparisons performed.

Table 4.4 shows the next grouping was for questions 1 through 10. Questions 8 through 10 required two steps of mental rotation and 8 through 10 had slightly more complex shapes to rotate. I also analyzed this group because I wanted to investigate whether there were any gender differences within smaller subsets of questions.

Table 4.4

Descriptive Statistics on Male and Female Students for Questions 1 through 10

	N	Min	Max	Mean	SD	Variance
PSVT:R female	13	0	10	6.92	2.842	8.077
PSVT:R male	13	0	10	5.77	2.774	7.692

Using SPSS 26, an independent sample t-test was conducted to compare the PSVT-R scores for questions 1 through 10 of male students (*M*=5.77, *SD*=2.057) and female (*M*=5.15, *SD*=2.035) students in the Academy of Technology. Again, there was not a statistically significant difference in the male and female scores, t(24)=1.048, p=0.305.

Lastly, I compared male and female scores on questions 1 through 20 with the descriptive statistics presented in Table 4.5. Questions 11 through 20 required two or three operations in order to picture the final shape and contained shapes and more complex 45-degree angled pieces.

Table 4.5

Descriptive Statistics on Male and Female Students for Questions 1 through 20

	N	Min	Max	Mean	SD	Variance
PSVT:R female	13	2	19	11.77	4.919	24.192
PSVT:R male	13	2	19	11.00	5.431	29.500

An independent sample t-test was conducted to compare the PSVT:R scores for questions 1 through 20 of male students (*M*=11.00, *SD*=5.431) and female (*M*=11.77, *SD*=4.919). Again, there was not a statistically significant difference in the male and female scores, t(24)=0.379, p=0.708. However, the difference between means for questions 1 through 20 was less than the gender difference in means for the entire 30 question test.

The last section that I analyzed and performed an independent sample t-test was to compare the PSVT:R scores for questions 21 through 30. These questions contained the most complex shapes and required two to three manipulations to obtain the final shape.

Table 4.6

Descriptive Statistics on Male and Female Students for Questions 21 through 30

	N	Min	Max	Mean	SD	Variance
PSVT:R female	13	1	7	4.00	2.160	4.667
PSVT:R male	13	0	9	3.46	2.774	8.936

The results for the independent t-test for questions 21 through 30 of the male students (*M*=3.46*, SD*=2.774) and female (*M*=4.00, *SD*=2.160). The mean scores did not show any statistically significant difference between the male and female scores with t(24)=0.526, p=0.603.

Chapter V: Discussion

The purpose of this mixed methods study of the Disassemble/Analyze/Assemble hands-on engineering unit is to investigate how students' experiences with engineering skills in this project affects their science and engineering self-efficacy and interests. This chapter includes a discussion of the major themes and findings from the study as well as their connections to engineering education research and Social Cognitive Theory research.

Interpretation of the Findings – Qualitative Data

RQ1: How and in What Ways Does the Exposure to Engineering Skills Through a Disassemble/Analyze/Assemble (DAA) Hands-on Engineering Unit Impact High School Girls' Science/Engineering Self-Efficacy and Interest

DAA Projects Encourage Problem Solving

The interview data for this study highlighted many opportunities this DAA project presented for the participants to successfully problem solve. During each stage of the project, students were required to problem solve in order to successfully move to the next stage of the project. Each participant had both an LED flashlight and a handheld fan to individually begin to develop engineering skills and curiosity of how products work. Many of the students expressed a sense of accomplishment at their ultimate success and how much they enjoyed "figuring things out". This sentiment was summarized by Sophie who stated, "My favorite part was putting it back together and making sure we had it right (post-DAA unit)".

Five of the nine students specifically discussed the switch on the fan, and the problem solving that was required to correctly place the switch so that it would complete the circuit. Comments by two of the students in the below average spatial group include, "so I had to go back and fix it" and "I thought the fan was difficult...every time you like accidently popped the switch off, you had to figure out how to put it back together." Six of the nine students, all from either average or below average spatial groups, specifically used the words challenging, difficult or hard to describe aspects of their two-day DAA unit experience. When I talked with Kayla about her experience and her confidence about her ability to take something apart at home, she stated

> I think that I could take it apart pretty easily but putting it back together would be the hard part and actually having it work. I felt like this is where I struggled a bit when we were taking apart the fa and the light. But I feel like I would probably work it out, till I got it right.

Results from this study highlighted problem solving experiences for the female students, which was similarly noted by engineering professors who have used the DAA or similar engineering teaching techniques at the college level. Sheppard (1992) when discussing a course at Stanford called *Mechanical Dissection* noted that one of the main purposes of the activities in the course was, "to develop resourcefulness and problem solving skills through labs that require students to reason about the function of three-dimensional objects" (p. 2). Beaudoin and Ollis (1995) developed a product and process laboratory class for first year engineering students at North Carolina State University. Their findings were that the course encouraged curiosity and problem solving as well as improved dexterity with the use of tools.

Other studies confirm that students like the opportunity to successfully problem solve, including one study by Baker and Leary (1995) where middle school girls expressed a desire to have laboratory experiences where they can discover “how things work”. The participants’ experiences in this study stand in contrast to some engineering design competitions where many of the groups do not find success in the larger task and not every child is given a chance to master the skill.

According to Bandura (1997) episodes of success and mastery experiences for a specific task produces an increase in self-efficacy and these authentic mastery experiences have a more powerful effect on self-efficacy than the other three factors affecting self-efficacy. Authentic educational experiences that potentially increase self-efficacy through mastery experiences is crucial since motivational researchers have noted that a higher self-efficacy correlates to a higher academic motivation and performance (Schunk & Pajares, 2002).

Qualitative inquiry revealed that initially four of the nine students were a little fearful about disassembling the computer, but after they began to analyze and remove components, they enjoyed the process. As they described their thinking process, they made a conscious decision to think positively and not negatively. Sophie summarizes this when she states, “And if you believe you can do it, you are going to do it. That’s what I have learned, and I have been a lot more successful after that.”

This is a good example of what Bandura (1996) describes as agency. Agency is the capacity that people possess to self-regulate and control their learning. This process of self-regulation becomes proactive and is applied intentionally as seen with the students deciding to think positively, believe in themselves and enjoy the learning (Bandura, 2008). According to Pajares (1997), the way a student interprets their performance can be of greater importance to self-efficacy than the proficiency of the performance itself.

Another important aspect of agency and self-regulation is the capacity of students to use themselves as models instead of comparing themselves to others. Results from this study showed that three of the nine students used “self-talk” to encourage themselves to persevere or change their mindset to “I can do this”. Using self-modeling helps students to envision positive outcomes and may provide the needed motivation to succeed during a challenging task (Bandura, 1997).

Science and Engineering Self-Efficacy

Even though the DAA unit provided opportunities for students to problem solve, this alone does not guarantee students’ increase in self-efficacy. Britner & Pajares (2006) discuss science self-efficacy

> Successful mastery experiences alone do not determine self-efficacy. Rather, individuals must cognitively process these experiences along with personal and environmental factors that include previously held self-beliefs, the perceived difficulty of the task, effort expended in the task, and help received in the completion of the task (p. 487).

One method to determine if changes occurred in science and engineering self-efficacy for these students is to compare their comments before and after the DAA unit. For example, Taylor (average spatial group) discussed her reasons for applying for the Academy of Technology. “I really wanted to be in the IT academy because I thought it was really cool how things like are put together and they work. I never understood it, but I wanted to know how (pre-DAA unit).” Prior to the DAA unit, Taylor had not disassembled any items. After the unit she stated, “I thought it was cool seeing how you could take everything apart and put it back together cause it shows how much like you have the skills to do it (post-DAA unit)." After the unit, she felt like she had the skills to accomplish a DAA project, which points to an increase in self-efficacy.

When discussing whether she had previously taken things apart Sophie (average spatial group) stated that, "I don't really mess with anything at home. I don't have the right tools for me to put it back together anyways. So if I don't have the right tools, why take it apart (pre-DAA unit)." Like Taylor, she did not have prior DAA experience. Sophie described her DAA experience by the following

> Not only did I learn the lesson that things aren't always as hard as they seem, but I learned to just see where things will take you. Just take them apart, put them back together, do your best and try your best to see which way it will turn. It will be fine. You'll end up where you need to be whether it takes you thirty minutes, thirty days, just keep going I guess (post-DAA unit).

Sophie stated that this experience inspired her to want to continue the experience at home and had even talked with her mom and brother about the idea. This is another example that shows a likely increase in science/engineering self-efficacy.

Of the four students who had never disassembled items in the past, three expressed the desire to disassemble other products in the future. The other student, Alexis (below average spatial group), stated that the only reason she did not want to disassemble anything was because she did not think it was safe for her young cousins she cared for at home. If she had not had that limitation, she thought that it would be fun and interesting experience.

There was one student who showed a change in their attitude toward pursuing a career in engineering. Prior to the DAA unit, Jordan (below average spatial group) stated, “I think I would like to do something in the science field (pre-DAA unit).” When I asked her again about her career interests, she explained, “I am hoping engineer…I just like things like hands-on, hands-on activities. I like doing that a lot. So just something toward that way. Engineering could be a possibility (post-DAA unit)”.

The other aspect of the qualitative data that pointed toward a possible increase in science/engineering self-efficacy is that eight of the nine girls described a sense of accomplishment or success they felt when completing the tasks and skills. According to Schunk and Gunn (1986), “the effects of task outcomes on self-efficacy depends on how they are cognitively appraised” (p. 243). Hannah (below average spatial group) explained, “I really enjoyed taking the computer apart cause it made me understand it, like what is connected to what and better understand the pieces and how they work (post-DAA unit).” When Hailey (above average spatial group) described her feelings about accomplishing the DAA tasks stated, “It feels pretty good. Yeah, it is a good sense of accomplishment because it is like, oh that’s cool, it works again. Like I just did that (post-DAA unit).”

Spatial Skills and Problem Solving

An additional aim of this study was to present the students with an opportunity to improve their spatial skills. Spatial reasoning was required for the disassemble/analyze/assemble process of the computer, fan, and flashlight. Additionally, the spatial lesson with the orthographic drawings and interconnecting cubes provided students with additional spatial training. Referring to the orthographic drawings and the three projections, Gabriella noted that, “Just seeing like top view, side view, you don’t know if maybe this block is hidden.”

All nine girls in this study could not remember having specific spatial training lessons in previous school classes. Even though there is no doubt that spatial skills had been used throughout their schooling, it is discouraging there is not more emphasis on spatial skills since they have been shown to be a significant predictor of STEM achievement (Wai et al., 2009). Spatial skills are also an important component for learning computer aided design programming, an essential tool used for engineering and architecture careers (Hamlin, et al., 2006). The good news is that spatial skills are moderately malleable and can be improved upon through various instructional methods that have been used at the K-12 as well as during college (Feng, Spence & Pratt, 2007; His, Linn & Bell, 1997; Sorby, 2012; Uttal et al., 2013; Wilhelm et al., 2013). When students are not exposed to these skills and do not have an opportunity to improve their skills through mastery experiences, it may hinder their future success in STEM fields (Shea, Lubinski & Benbow, 2001).

DAA Project Encourages Science Connections

Findings in this study point to the conclusion that students were able to make cognitive connections between science teachings on electricity and circuitry and their practical usage in the LED light and fan. Seven of the nine students expressed learning about these concepts in science class but that the hands-on experience brought those concepts to life. Chloe reveals, “The day before I had my physics class and we started doing electricity and they mentioned resistors which is why I was so excited when I found one.”

Eight of the nine students specifically mentioned technical processed they had not previously considered. For instance, four of the students mentioned the presence of multiple fans used in a desktop computer. Other students commented on learning about the interactions of various computer components. Hannah stated, “It made me understand it, like what is connected to what and better understand the pieces and how they work.” Chloe referred to the fan and “seeing how the motor was connected to the circuit.” Six of the nine students emphasized the length of time they personally were able to experience hands-on learning with each of the products and how this increased their learning and connections to previously learned science concepts. Three of the nine students noted that they found the project beneficial because they could transfer this knowledge to diagnose and fix products in the future. Gabriella stated, “I find it useful…so if something does break and maybe my home PC, I can like look and be like, “that’s disconnected””.

This coincides with research and journal articles written about reverse engineering and DAA projects at the college level. One article describes the use of DAA in a freshman level engineering course at the University of Texas at Austin and how the hands-on experience of this type of product allows students to become familiar with the mechanical and electrical workings of products (Barr, Schmidt, Krueger & Twu, 2000). Beaudoin and Ollis (1995) found that at the college level, the dissection experiences encouraged students to ask questions about how things worked and helped them to understand the material from the lectures better.

According to *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* (NRC, 2009), one of the advantages of engineering education is improved achievement in mathematics and science. As students make connections and begin to feel that they understand previously learned concepts more thoroughly, this increases self-efficacy. Each opportunity for students to successfully connect their learning to previous learned concepts is another chance for a mastery experience, which strongly predicts an increase in self-efficacy (Britner & Pajares, 2006). This is encouraging since science self-efficacy is a good predictor for science achievement and science related interest (Pajares, 1997).

According to Social Cognitive Theory, acquiring knowledge occurs within a relationship described as the triad reciprocal causation. The components of this triad are personal, environmental and behavioral and the dynamic interplay between these components is how researchers within Social Cognitive Theory believe knowledge occurs (Bandura, 1986). "Research shows that self-efficacy beliefs (personal variable) influences achievement behaviors (choice of tasks, effort, persistence) in that efficacious students are more likely to choose to engage in tasks, expend effort, and persist to overcome obstacles and succeed" (Schunk & Zimmerman, 1997, p. 196). The environmental component could include a new teaching method or as is the case in this research study, a novel hands-on learning experience with various products (Schunk & Zimmerman, 1997).

Taylor's description of her experience of the DAA process provides a good example from the data of this triad reciprocal causation.

> I thought it was cool seeing how you could take everything apart and put it back together cause it shows how much like, you have the skills to do it. It's not something like super high tech. You can take it apart, put things back together and then you start small and you can get bigger and make a lot of bigger things. It was cool.

Her personal component of the triad could be a sense of empowerment she received from the experience and her belief that she could tackle larger projects. The behavioral component would be the skills she used to problem solve and make cognitive connections with science concepts she had been exposed to previously. The environmental component is the products the students disassemble and explore as part of the DAA project.

Self-Efficacy and Science, Engineering or Technical Interests

This study suggests that the DAA activities increased the students' interest in science and engineering as students became more interested in "how things work". As students combined their previous science or computer knowledge with the DAA project, seven of the nine female students specifically mentioned that they became more curious about product designs and internal components. This DAA hands-on engineering experience appears to have increased student confidence and interest in problem-solving and the desire to diagnose why products stopped working.

Qualitative inquiry in this study revealed that students enjoyed the hands-on learning experience and that five of the nine students desired to perform another DAA project in the future. Within Social Cognitive Theory, interest is driven by a combination of self-efficacy and outcome expectations (Bandura, 1997). Applying SCT to the DAA project, the girls' self-efficacy appeared to increase as they mastered the skills needed for the project and they were able to make connections with previously learned science concepts. Students also expressed the enjoyment of the projects and a desire to repeat similar experiences in the future, which points to the female students feeling that a future outcome of engineering inquiry would be a positive experience.

Four of the interviewees in the study specifically stated that role models were the reason that they had initially taken a computer science course or the reason they attend the Academy of Technology. Hailey sums it up as she describes her role models,

> One is my cousin. She works at the NSA. They recruited her out of high school and she gets to do all this cool stuff. The other is from the TV show Arrow and I saw Felicity Smoke and I was like, "that's so cool, like I want to be able to do that." So I took a programming class last year. I liked it so I just kind of kept going.

As models, real or from the media, are perceived to be successful in school or in a specific career, this can motivate students to pursue that path and believe in a positive outcome for their perseverance (Schunk & Usher, 2019).

RQ2: How Does an Engineering DAA Unit Affect High School Girls' Consideration of a Career in Either Science or Engineering?

Career Considerations

As mentioned above, a notable finding of this study is that role models motivated many of the participants to consider science career options and pursue science or technical classes. These role models ranged from female television show and video game characters, parents, brother and a cousin to a male computer programming teacher. Even though it may not seem that female role models in the media have brought an increase of female representation into the STEM careers, interviews with these students provided a unique window into how these role models significantly impacted their lives. Six of the nine students specifically mentioned role models as a motivating factor in their lives and career considerations. This is consistent with other qualitative research studies of self-efficacy which show that role models play an important part in science and engineering interest for many students (Britner & Pajares, 2006). Even though some researchers consider mastery experiences to have more significant impact on self-efficacy than the other three components, it is important not to discount the importance of vicarious experiences for some students (Bandura, 1997).

Students were not only encouraged to pursue technical fields because of these role models, but they also seemed to be motivated to persevere through difficult and challenging circumstances. Hailey commented on how her role models motivate her

> It just inspires me to work harder and so I can go out there and do that thing and be like them…but I think those people really show me like, that it is possible to be the best instead of just settling for mediocrity.

This is in line with Social Cognitive Theory researchers who have noted people are more likely to model behavior or skills they observed in individuals with whom they identify (Schunk, 1989). These vicarious experiences through role models help motivate and encourage perseverance to students who perceive that they are capable to attaining the goals of their role model (Bandura, 1997). Bandura (2001) has also observed that a person's models also influences and shapes values and behavior to form their own reality.

There are many different experiences that affect a person's career decisions and most often involves the culmination of years of experiences rather than just a single event. Even though the data supports the hypothesis that the DAA project helped increase female students' science/engineering self-efficacy and interest, there is not enough definitive evidence to claim that the DAA project affected students' career considerations. Prior to the DAA project, most of these students were already planning on either a career within one of the STEM fields or at least perceive the importance of learning about computers and programming within their chosen career path.

Also prior to the DAA project, six of the girls expressed a desire to pursue a college degree in a field that they perceive as helping people. It was encouraging to know that all nine female students held a positive view of STEM majors as careers that help people and perceived the fields as important to society. Sophie even described the job of a scientist as "to preserve life".

According to Lent, Brown and Hackett (1994), the interplay between self-efficacy, outcome expectations, interest and goals have a strong influence on career considerations. In addition, other Social Cognitive Researchers point to academic self-efficacy as a key factor in career choice. Children who have a secure sense of academic efficacy judge themselves to be efficacious for careers in science and technology, educational and medical fields, artistic and literary pursuits…The mediation through academic achievements is stronger for girls that for boys (Bandura, Barbaranelli, Caprara; & Pastorelli, 2001, p. 197).

RQ3: How Does the Impact of Being Exposed to Engineering Skills Through a DAA Hands-On Engineering Unit Differ Among Female High School Students Whose Scores on the Purdue Spatial Visual Test (PSVT:R, Guay, 1976, Yoon, 2011) are Either Above Average, Average or Below Average?

Differences Among the Spatial Groups

The findings of this study showed more similarities than differences among the spatial groups, but there were differences. Those in the above average group seemed more confident with the disassembly task and had more experience with disassembling complex products in the past as compared to the below average spatial group. One of the girls in the below average spatial group suggested that the teacher model the disassemble/analyze/assemble process along with their students before the students are given a more independent day where they use the DAA process on another product. Those in the average and below average spatial abilities groups found the DAA activity with the computer more challenging and required more problem-solving activities than the above average group.

Observational learning is a key concept of SCT and is a very common avenue where we obtain and master new skills (Bandura, 1986). SCT postulates that when a student acquires knowledge or a skill through observational learning, they observe the model and code a mental picture of the information for cognitive retention. Then the student must be able to reproduce this knowledge and be motivated to do so (Bandura, 1986). An engineering education lesson like the DAA project is a good example of observational learning as students work at the same table and help each other with various tasks.

Interpretation of the Findings – Quantitative Data

RQ4: Do Female Students Who Have Elected to Take Computer Courses in High School Show Differences in Spatial Rotation Skills as Compared to their Male Counterparts on the Purdue Spatial Visualization Test (PSVT:R, Guay, 1976; Yoon, 2011)?

PSVT:R by Gender

Table 5.1

Purdue Spatial Visualization Test: Rotations (PSVT:R) Scores by Gender

Female Students	PSVT:R Score	Race*	Male Students	PSVT:R Score	Race
Chloe	25	C	Liam	28	C
Gabriella	25	C	Justin	26	Asian
Hailey	24	AA	Noah	24	C
Samantha	20	Asian	Gabriel	18	AA
Sophie	17	AA	Tyler	18	H
Taylor	17	C	Isaiah	13	AA
Kayla	16	C	Lucas	13	Asian
Lily	16	C	William	12	C
Naomi	13	C	Oliver	11	C
Jordan	12	C	Ben	10	AA
Hannah	11	Asian	Brandon	7	C
Emily	9	Asian	Caleb	5	AA
Alexis	3	H	James	5	Asian

*C=Caucasian, AA=African American, H=Hispanic

Table 5.2

PSVT:R Mean Values for Portions of Test with Independent Sample t-test p-values

Test Questions	Female Mean	Male Mean	T-Test p-value
1-7	5.15 (7)	4.31 (7)	0.302
1-10	6.92 (10)	5.77 (10)	0.305
1-20	11.77 (20)	11.00 (20)	0.708
21-30	4.00 (10)	3.46 (10)	0.603
Entire Test	16.00 (30)	14.62 (30)	0.625

An additional aim of this study was to analyze scores from the PSVT:R (Guay, 1976; Yoon, 2011) scores and determine if the males outperformed the females with mental rotation skills. The findings of this study revealed that male and female students had no statistically significant difference between the mean scores on the PSVT:R (Guay, 1976; Yoon, 2011) for this sample in the Academy of Technology. This was contrary to most of the research on gender differences in mental rotation skills.

The PSVT:R (Guay, 1976; Yoon, 2011) is known to be a long and challenging exam (Maeda & Yoon, 2013) and I did adhere to a strict 30 minute time limit for the test. Therefore, I investigated the means for different question numbers and lengths of the test. Specifically, I began with questions 1 through 7 because in order to answer those questions it only required one mental rotation operation. I then proceeded to examine means for questions 1-10 because these questions required either a one or two step mental rotation, but the shapes remained relatively simple. I examined questions 1-20 to examine the mean scores on a shorter version of the test that still requires some complex rotations. The last section I examined were questions 21-30 because this particular subsection required at least two or three rotations to answer, and the objects were the most complex of the test and at times, difficult to imagine mentally.

Using SPSS 26, I ran independent sample t-tests for the different ranges of questions (see Table 5.2). Even though there was never a point where the t-test result showed a statistically significant gender difference between the means, the female students showed a higher percent difference in mean scores for questions 1-7 combined. After that point, the means exhibited a pattern of gradual convergence up until the analysis of questions 1-20. The gap only increased slightly from the t-test results of questions 1-20 to that for the entire 30 question test.

In a meta-analysis of forty primary studies of PSVT:R (Guay, 1976) scores comparing genders, Maeda and Yoon (2013) showed that male students consistently outperformed female students. There have been studies showing this gap lessoning when students were given more time on the tests a decreased gap when given a computer version of the test, rather than a pencil and paper version (Maeda & Yoon, 2013). However, other studies have not found these factors to change the trend of male students outperforming the female ones (Masters, 1998; Titze, Heil; & Jansen, 2008)

When I originally gave instructions for students to take the PSVT:R test (Guay, 1976; Yoon, 2011), I explained that I was looking for whether there was a difference between students in the Academy of Technology and those who were not. Other researchers have proposed that the gender differences on mental rotation tests are related to female students' affective states and self-efficacy, where their psychological status can be affected by common stereotypical beliefs (Cooke-Simpson & Voyer, 2007). It is possible that these girls in this study possessed a higher spatial self-efficacy and were not affected by the stereotypical thinking.

Lastly, it has been proposed that previous spatial experiences can highly affect their spatial reasoning scores on the PSVT:R (Maeda & Yoon, 2013). A high percentage of the girls in this study had previous experiences with disassembling various products and had taken a least one year of a computer science course. This may also help account for the mean scores being similar between the two gender groups.

Limitations

Although the findings of this study indicate that the DAA project had a positive effect on the female students' science and engineering self-efficacy and interest, the impact on career considerations appear to be limited. Since research at the college level has shown for female students the DAA project had increased their motivation and desire to continue in the engineering field (Beaudoin, 1995), I hope that this same trend will be true for those female students who are already considering engineering as a college major. It is important that students continue to have experiences where they can develop their science and engineering self-efficacy by experiencing authentic educational opportunities to develop these skills. This provides further evidence that continuing engineering education within the framework of K-12 classrooms is essential so that students have opportunities to develop those skills throughout their education.

Another limitation of this study is that the study was conducted in April and May, which was toward the end of the school year. The advantage was that the classroom instructor had completed most of his planned curriculum, so he and the school allowed me to use his classes for this study. However, the limitation is that it was very difficult to motivate students to return their parental permission forms in order to participate in the study. Even with teacher encouragement, there was still a very limited number of students who were willing for their PSVT:R (Guay, 1976; Yoon, 2011) scores to be used in the study (13 male and 13 female students).

The conclusions of this research were framed within the context of Social Cognitive Theory. Using the same data from interviews could produce different conclusions if viewed the lens of different theoretical frameworks. The conclusions could also be different if a researcher used another method rather than a priori directed content analysis for the qualitative data.

Implications and Suggestions for Further Research

This was an exploratory study into the use of a DAA project in high school classrooms. There is very little data on their uses at this level, and much more research is required. Larger scale studies are necessary to further investigate DAA's potential because the sample size was small in this study. However, this study showed significant potential for this engineering education project to be used at the high school level to increase science and engineering self-efficacy and interest, especially for students who do not have the opportunity to participate in STEM camps or STEM related activities outside of school hours.

The lack of emphasis on spatial reasoning educational opportunities for these students was discouraging. Even though there is research emphasizing the importance of the spatial skills for many STEM fields and an emphasis on this training for many introductory engineering classes in college, there remains a lack of emphasis on spatial skills at the K-12 level.

There has been an emphasis on engineering design building competitions at the middle school level. However, there appears to be few opportunities at the middle school for students to explore products through a DAA or reverse engineering project. Middle school students could benefit from this type of hands-on engineering unit. They would just require more modeling from teachers and closer supervision with the tools. Finding methods to encourage interest and self-efficacy in STEM field for female students should be a priority, especially since throughout the high school years, the percentage of male students who plan on majoring in STEM fields remains constant. However, this is not true for the girls, where there is almost a 20% drop in interest and plans to major in a STEM field (Sadler et al., 2012).

APPENDIX A:

PRE-DAA INTERVIEW PROTOCOL

Background Questions:

1. Where did you attend elementary and middle schools?
2. What was your favorite subject during middle school? What have been your favorite classes in high school?
3. What about it/those made it/them your favorite subject(s)?

School Science Experiences

4. Can you tell me the types of topics you studied in science in middle school and high school?
5. What were your favorite parts of science classes?
6. There are many different ways teachers can teach science, from using the book, worksheets, lectures, videos, experiments, group learning, assigning homework, assigning projects, etc. Can you tell me what sorts of ways you learned science in middle and high schools? (have student describe typical classes as much as possible)
7. Can you tell me about different methods that seemed to help you learn and remember science concepts during class?
8. What methods helped you learn and remember science outside of the classroom?
9. Do you ever use the internet to help you when you are struggling to learn something in science? What types of internet sites have you found the most useful for science?
10. Do you and your friends help each other with your homework when you are struggling? Do you call or text each other or do you work on it at school?
11. Tell me about some experiences you have had working in groups. Do you usually end up doing jobs in the group that you like or those you dislike? Do you feel your projects are better when you work alone, or when you work in a group? Explain.
12. How do you feel about your ability to complete science assignments and take science tests? How do you feel about your ability to do science labs or experiments? Are there aspects of science that you would be interested in learning about outside of science class?
13. What aspects of your science abilities do you feel confident about?
14. Are there aspects of your science abilities that you don’t feel very confident about? What part of doing science might make you feel a little stressed? What aspects of your science abilities or knowledge do you think you could work on improving?

15. Has a teacher ever complimented you or made comments about your science abilities or your ability to learn science? Has a parent or relative ever complemented you regarding your science knowledge or interest?
16. What would you say are the sorts of jobs that scientists have? Which of those jobs sound interesting to you?
17. Can you tell me about the types of projects that engineers work on?
18. Tell me about your ability to do math homework or take math tests? If you were to compare yourself to your friends, would you describe your ability to solve math problems as toward the top, middle or lower range?
19. What type of mathematics problems do you struggle with the most? What types do you find the easiest?
20. On a scale from 1 to 10, how confident are you in using mathematics in solving science problems? Describe the types of math problems you do in science.

Family and Friends

21. On a scale from 1 to 10, how much do you value your friends' opinions about school, academics and the classes you choose to take?
22. On a scale from 1 to 10, how much do you value your family's opinions about school and academics and the classes you take?
23. Does your mom or dad work in a science, technology, mathematics or engineering job? Did either of them study science, technology, engineering or mathematics when they were in college?
24. Do any of your relatives have jobs related to science, technology, engineering or mathematics? Have you ever talked with them about their jobs?
25. Would you describe your friends as good at mathematics and science? What types of things do you think your friends would say if you told them that you would like to become a scientist? Or a computer programmer? Or an engineer? An artist? A journalist?
26. What are the types of things your mom might say if you said you would like to become a scientist? A computer programmer? An engineer? An artist? A journalist? What are the types of things your dad might say?
27. Tell me about the types of jobs your girlfriends are interested in? What about the boys in your class? Do you notice any differences?
28. What sorts of things do you do with your family on the weekends? What sorts of things do you do with your family during vacations?

Society

29. Who are the women that you respect and look up to in your life?
30. When you think about the types of jobs that you would find interesting to do in your life, what influenced you to consider those types of jobs?

Play

31. Tell me about the types of things you like to build or create?

32. Tell me about the kinds of card games or board games you play? Who do you usually play these games with?
33. Tell me about your hobbies. Can you tell me about how you became interested in ……(those hobbies)? Who encouraged you in …..(those hobbies)?
34. Describe the computer games you like to play? Do you play these with others online?
35. Did you ever take anything apart just to see how it works? Can you tell me about these experiences?

APPENDIX B:

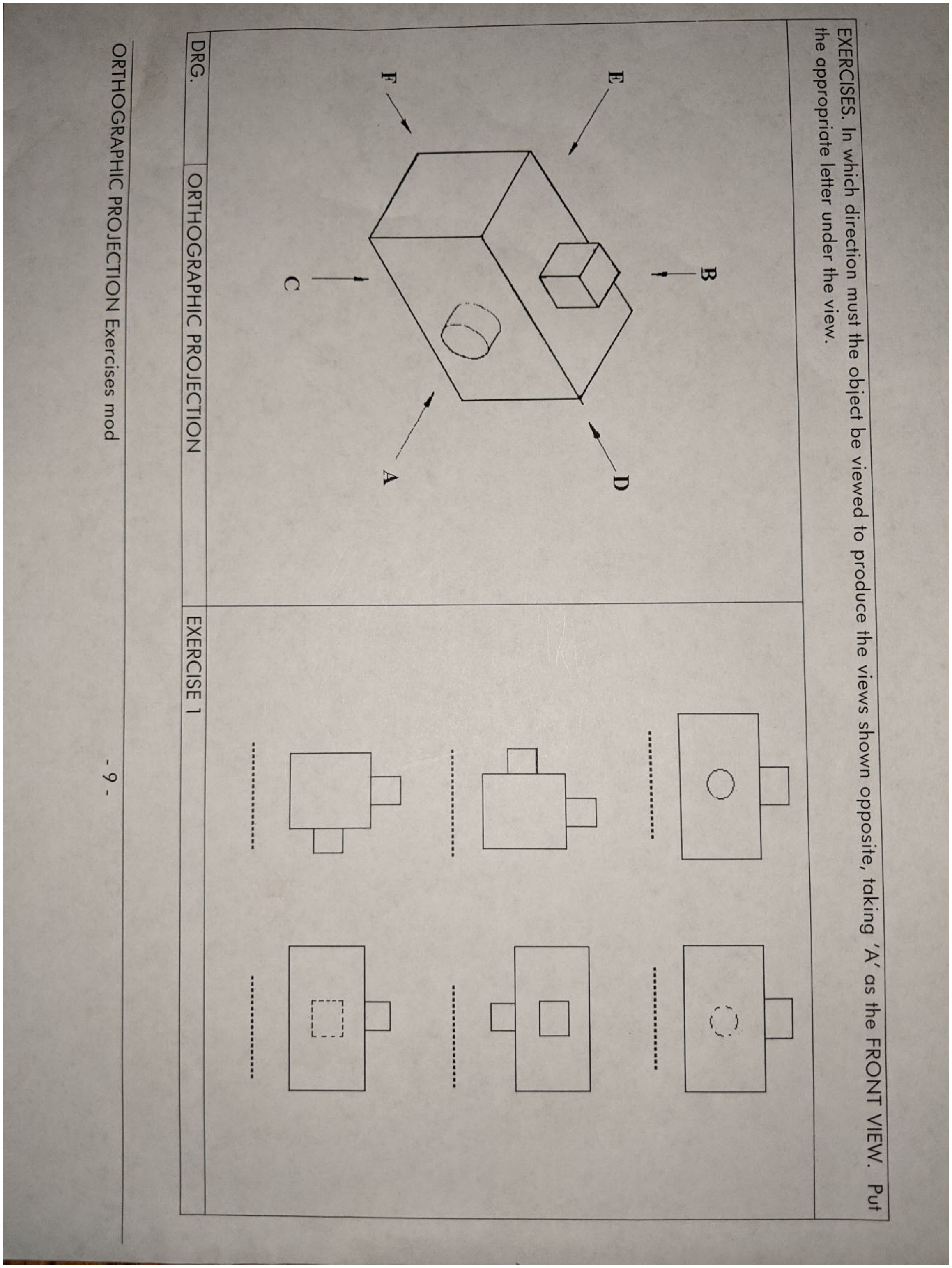
POST-DAA INTERVIEW PROTOCOL

Introduction

1. Tell me about your experience taking apart the computer. What did you find interesting? What was something new you learned?
2. Tell me what it felt like to take something apart.
3. Tell me about your experience taking apart the LED light or the handheld fan. What part of it did you find interesting? What was something new you learned?
4. Tell me what it felt like to put something back together and have it work.
5. What other similar projects would you like to see in school?
6. Is there anything you would like to see changed or added to the computer dissection? How do you think this project could have been better?
7. Is there anything you would like to see changed or added to the LED light or fan disassemble/analyze/assemble project? How do you think the project could have been better?
8. Have you ever taking anything apart at home? Is there anything at home you would like to take apart now? On a scale of 1 to 10, 10 being very confident, how confident are you that you could take something apart and analyze how it works? What do you think would help increase your confidence level?
9. Have you ever used YouTube to help you learn how to do something? Describe that to me.
10. Tell me about your experience with the spatial lesson. Tell me about any other spatial lessons that you have had in the past.
11. Tell me about your experience with the rotation test. Have you ever worked that type of problem before?
12. Tell me about the group you worked with when taking apart the computer. Would you like to change anything about that group?
13. Tell me your experience working with your partner when you took apart the light or the fan? Is there anything you would like changed with that group?
14. Do you find you prefer working in a small group or alone on projects like these? Does it matter who is in the group with you? Does it matter to you or do you see any differences if the group is all girls or if the group contains both male and female students?
15. Tell me about experiences working in groups in other classes.
16. If you had the time, describe to me some of the things you are curious about and would be likely to watch a video about or Google information about.
17. What are the types of careers you are interested in? Is there anything you have learned in school that makes you more interested in one career over another?
18. Tell me about how your career options are affected by friends? Family? Relatives?
19. Are any of your relatives scientists? Are any engineers? Are any computer programmers?

APPENDIX C:

ORTHOGRAPHIC DRAWINGS PACKET

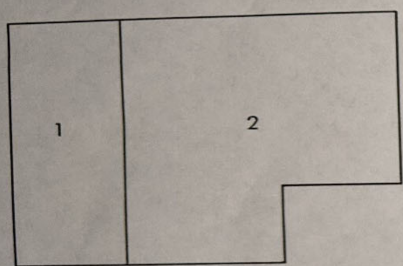

EXERCISES. In which direction must the object be viewed to produce the views shown opposite, taking 'A' as the FRONT VIEW. Put the appropriate letter under the view.

DRG. | ORTHOGRAPHIC PROJECTION | EXERCISE 1

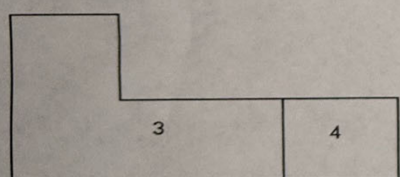
ORTHOGRAPHIC PROJECTION Exercises mod

- 9 -

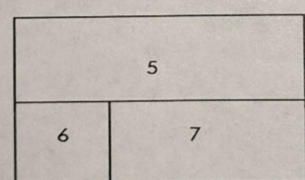
XERCISES. Study the two drawings and complete the table by matching the numbered surfaces of the orthogonal drawing with the ttered surfaces of the isometric drawing.



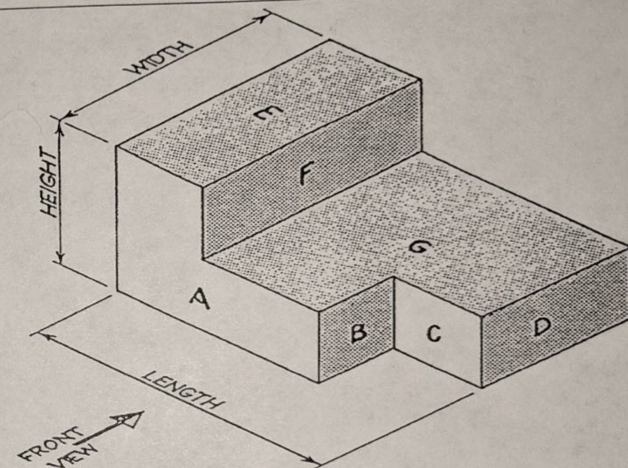
TOP VIEW



FRONT VIEW

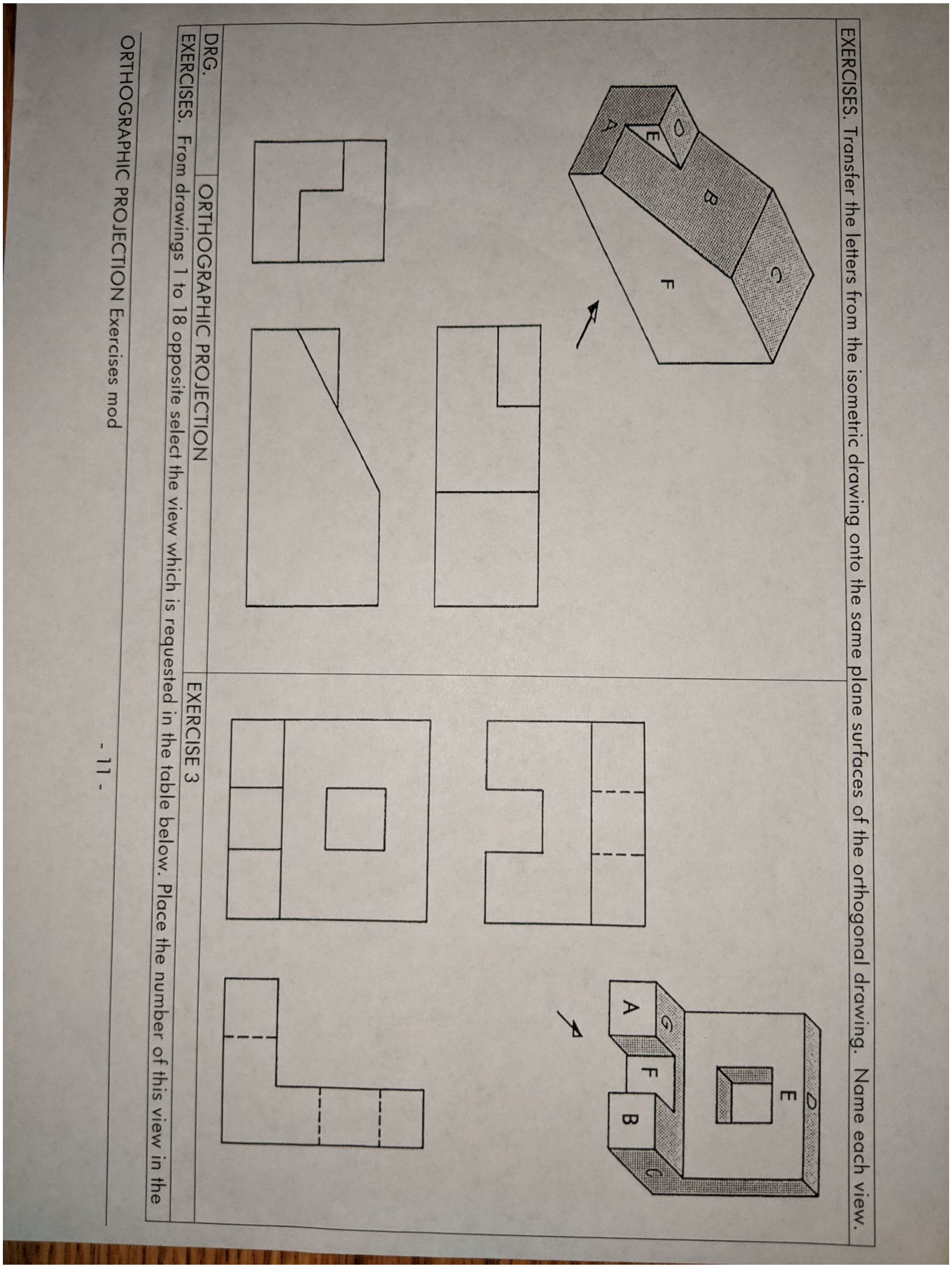


SIDE VIEW



A	B	C	D	E	F	G

DRG.	ORTHOGRAPHIC PROJECTION	EXERCISE 2


EXERCISES. Transfer the letters from the isometric drawing onto the same plane surfaces of the orthogonal drawing. Name each view.

DRG.	ORTHOGRAPHIC PROJECTION	EXERCISE 3

EXERCISES. From drawings 1 to 18 opposite select the view which is requested in the table below. Place the number of this view in the

ORTHOGRAPHIC PROJECTION Exercises mod

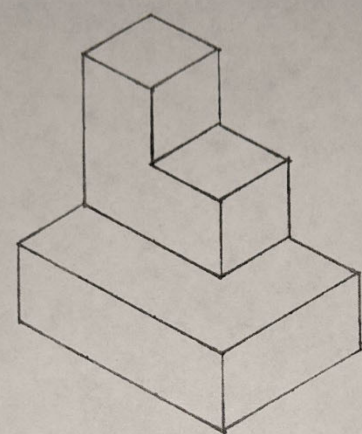
- 11 -

Name: ______________________ Date: ______________ Class: ____________________

Orthographic Drawings Worksheet

Instructions

Draw the orthographic projections of the following object.

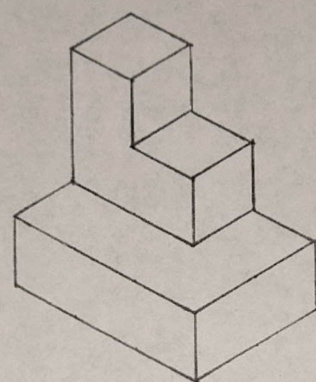


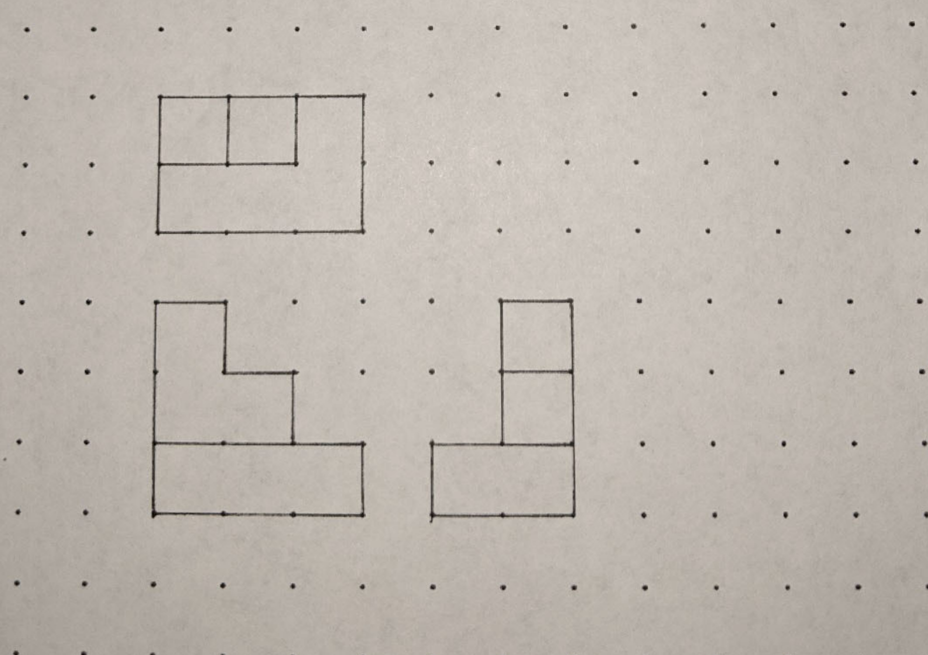
Name: ______________________ Date: ______________ Class: ____________________

Orthographic Drawings Worksheet Answer Key

Instructions

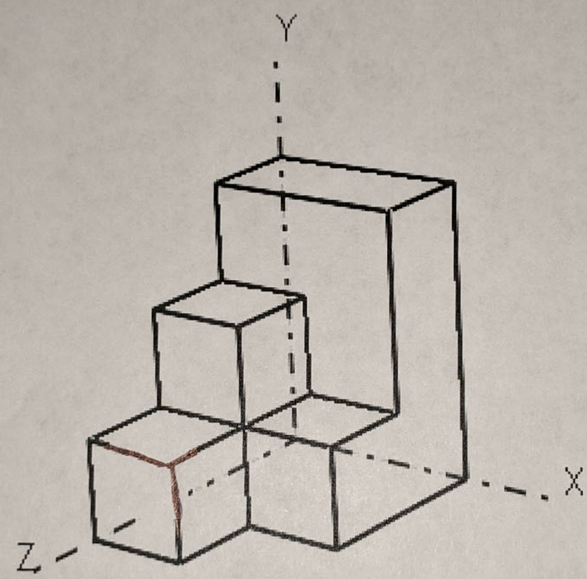
Draw the orthographic projections of the following object.

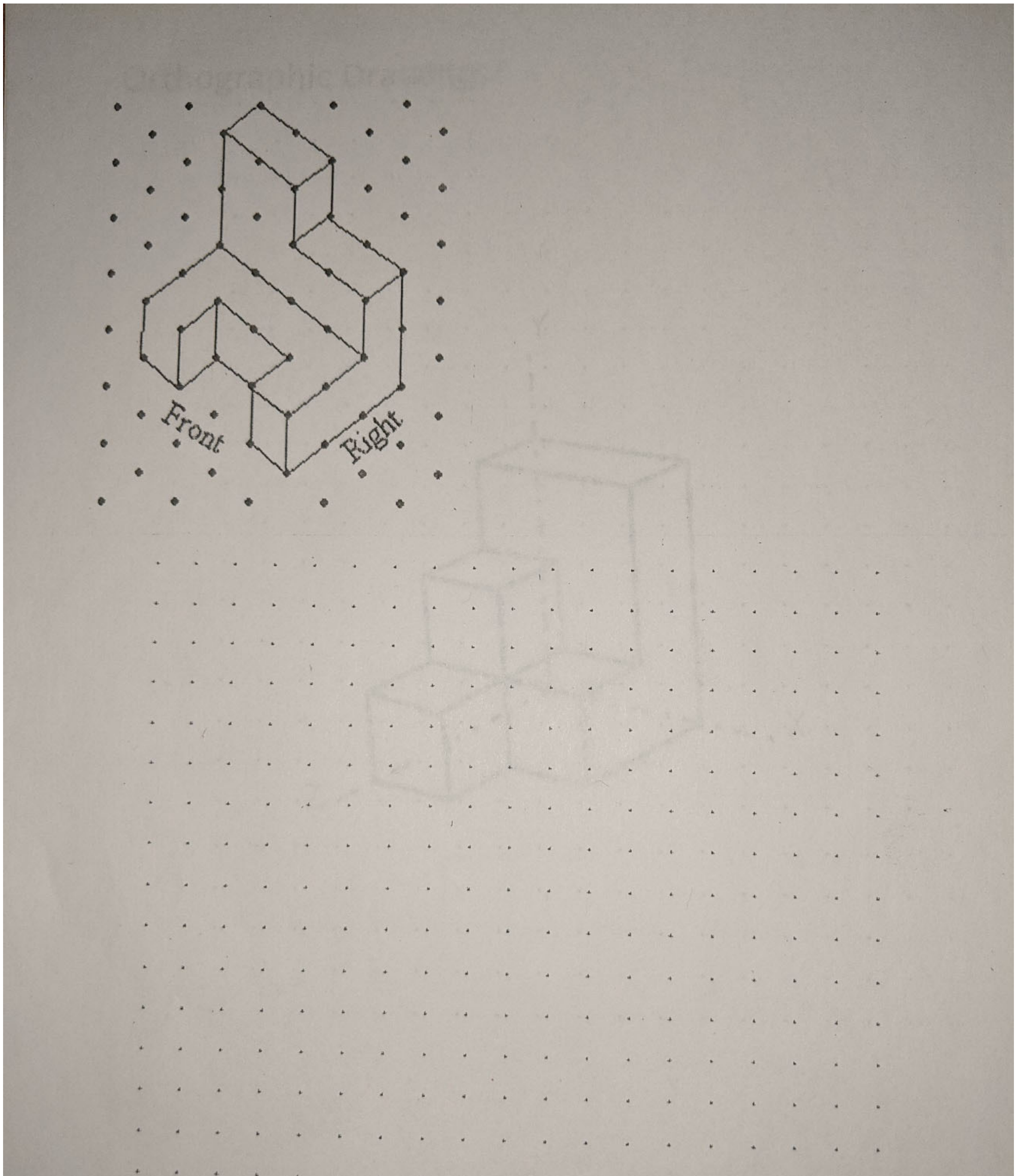




Seeing All Sides: Orthographic Drawings Activity—Orthographic Drawings Worksheet Answer Key

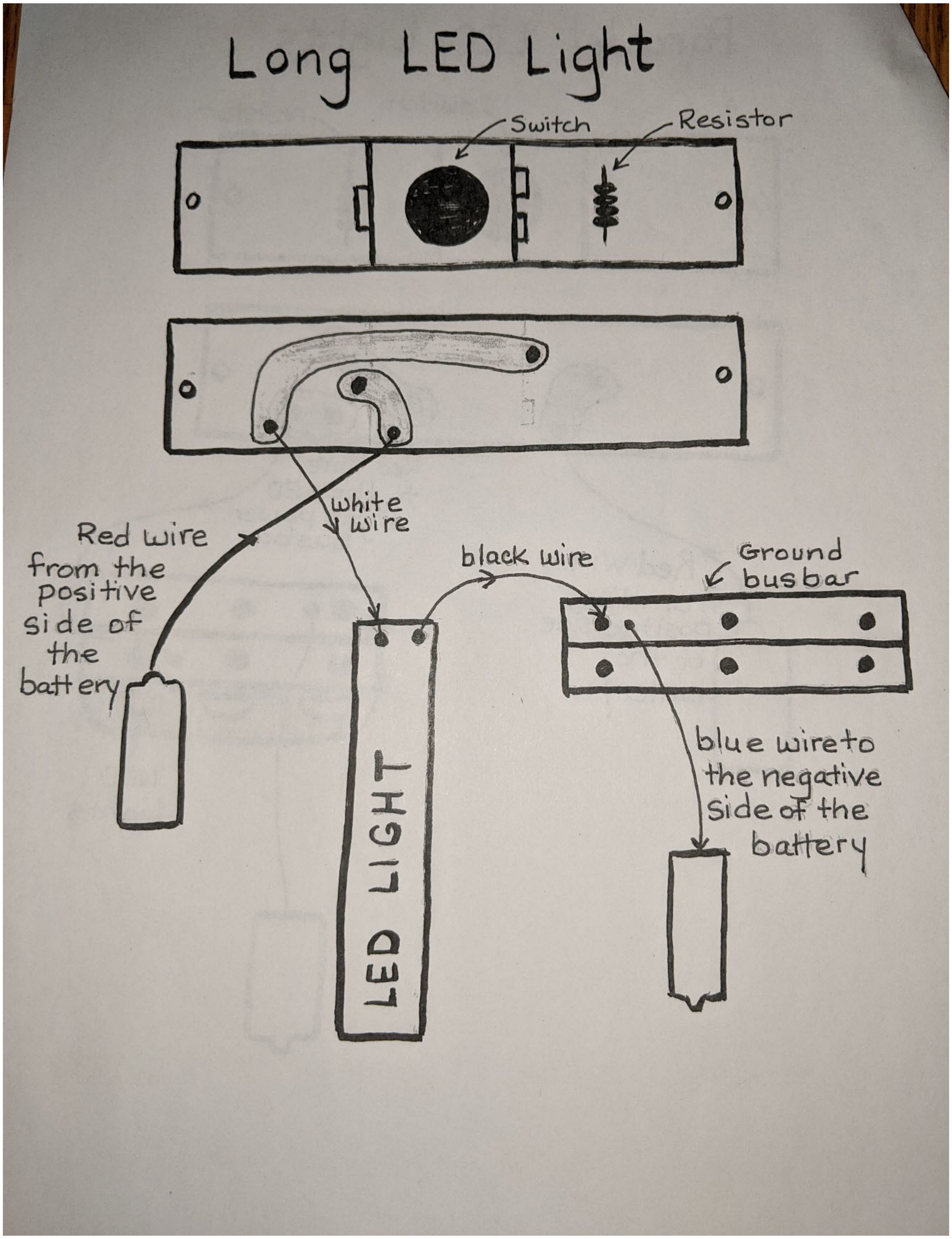
Orthographic Drawings

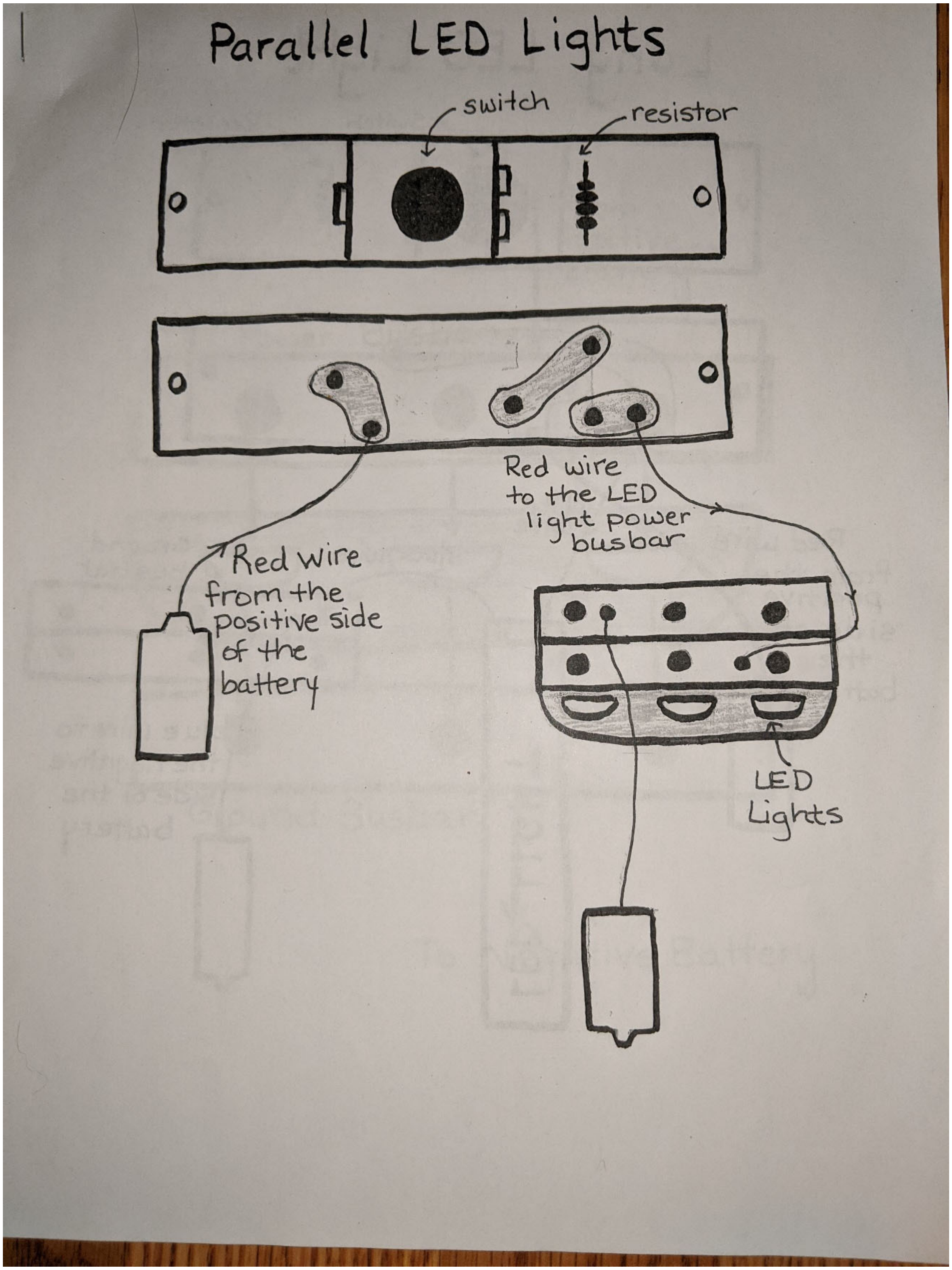


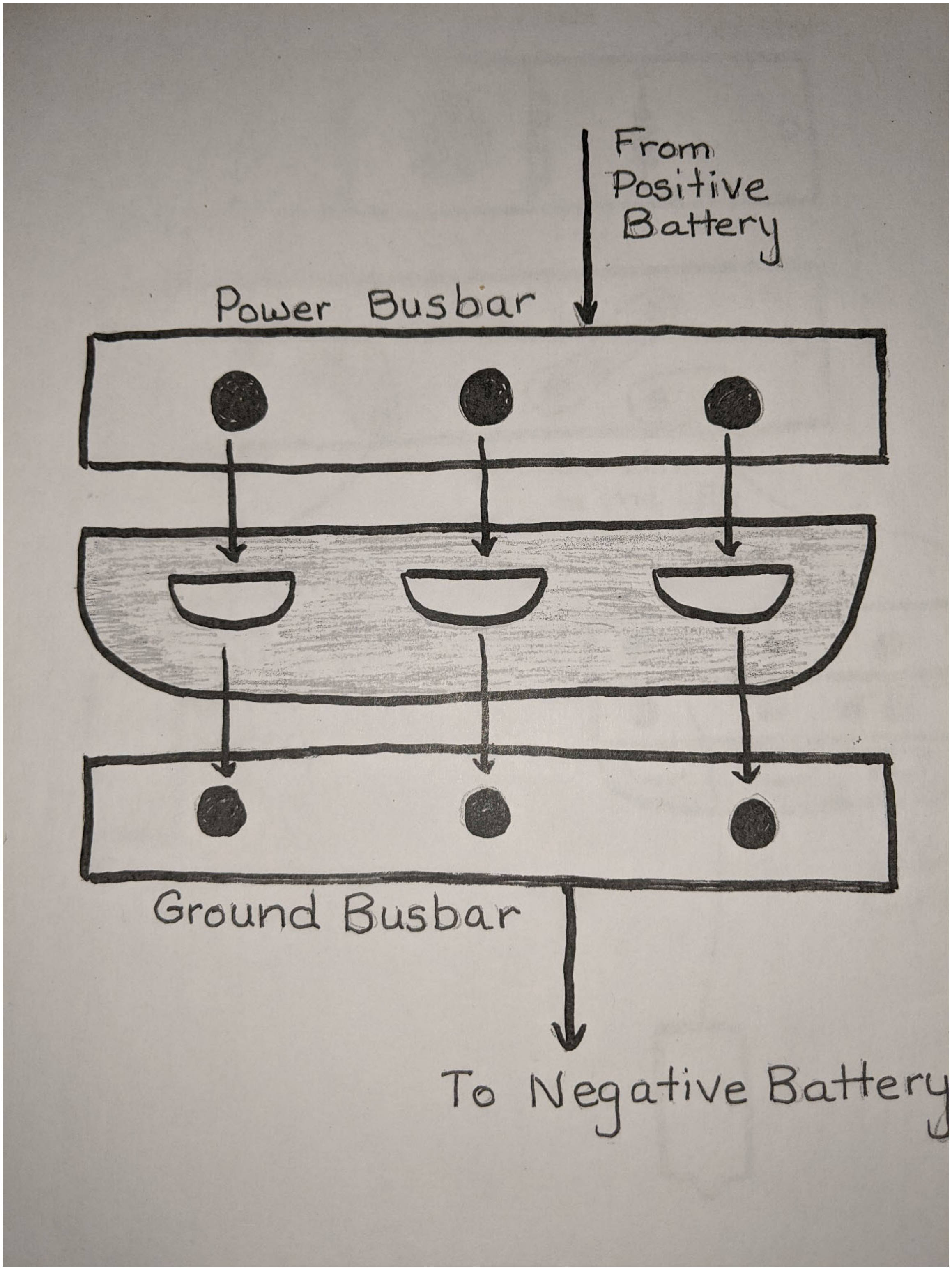

Front
Right

APPENDIX D:

LED LIGHT SERIES AND PARALLEL CIRCUITS




Parallel LED Lights
switch
resistor
Red wire to the LED light power busbar
Red wire from the positive side of the battery
LED Lights


From
Positive
Battery
Power Busbar
Ground Busbar
To Negative Battery

References

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Vita

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1983 – 1987	**Graduated with Bachelor of Science in Nursing**

Professional Positions Held

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