Design Thinking in a Seventh-Grade Classroom: A Case Study

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By Matthew S. Campbell

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Dedication

This dissertation is dedicated to my family who have shown a tremendous amount of patience and support throughout this doctoral program. Specifically, I want to thank my parents who made it a priority and sacrificed time and money to ensure I pursed higher education. To my children Emma, Luke, and Cole, thank you for sharing your play room with me and allowing me time upstairs to complete this work. I will take great joy in watching you pursue your educational and life goals and promise to be there to support you at every turn. Finally, and most importantly to my wife Alesha. Words cannot begin to express the importance of your love and support through this process. When I wanted to quit or did not think I was capable, you encouraged and supported me. Your selfless acts of kindness to provide the time and space needed to complete this doctoral program and dissertation are much appreciated and cherished. Together we have persevered and have in many ways accomplished this together. I love you and thank you for unconditional support.

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ABSTRACT OF THE DISSERTATION

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Abstract

The Fourth Industrial Revolution is described as the reshaping of manufacturing using advanced technology, the improved use of robotics, augmented and virtual reality, mining of data and data analytics, biotechnology, and the increased ability to transform three-dimensional images into the physical world. The exponential rate at which these technological changes are occurring is adding to an ill-defined complexity of problems, creating an urgency for a workforce globally and nationally that can respond. The current traditional linear model of education is failing students by not providing the innovative learning environments needed to acquire the technological, work, socioemotional, and civic skills necessary for students to effectively engage in this complex work and community environment. Design thinking is one innovative pedagogical approach that may provide a learning environment for students to gain the skills necessary to engage in the Fourth Industrial Revolution. The purpose of this study was to examine the use of design thinking in a seventh-grade technology-education classroom to determine. A qualitative case-study methodology was used to explore the pedagogical approach, detect the presence or absence of core elements of design thinking, and observe benefits or

limitations. The Stanford Design School model of design thinking was implemented as a conceptual model for observation and data analysis. Study results provide a detailed example of design-thinking integration in a K–12 classroom. Additionally, the data supported varied evidence of the presence of design-thinking stages. Consideration of the benefits and limitations of design thinking on teacher instruction and student learning emerged.

Keywords: design thinking, constructionism, Fourth Industrial Revolution, middle school pedagogy, future ready skills

Signature of Investigator__Matthew S. Campbell___ Date_7/9/019___

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Chapter 1

Introduction

Statement of the Problem

As students begin to leave the educational structure of high school and college, they are entering a global work and community environment in which they will face complex and ill-defined problems. The world of work, the global economy, and complex issues facing communities are rapidly changing and vastly different from what students in previous decades faced. The World Economic Forum (2018) states people are now living in the Fourth Industrial Revolution, which has begun to shape and influence the job force and has become a reality for workers and companies around the world. Although early in its infancy, The Fourth Industrial Revolution influence is described as the reshaping of manufacturing using advanced technology, the improved use of robotics, augmented and virtual reality, mining of data and data analytics, biotechnology, and the increased ability to transform three-dimensional (3-D) images into the physical world (Baur & Wee, 2015; Sheninger & Murray, 2017). The exponential rate at which these technological changes are occurring is adding to an ill-defined complexity of problems and creating an urgency for a workforce globally and nationally that can respond (Brophy, Klein, Portsmore, & Rogers, 2008). Due to these dramatic and fast-moving advances in technology, demand is growing for new and innovative jobs, skills sets that are not currently or clearly defined, and the necessity for a workforce that can quickly adapt and learn new skills (World Economic Forum, 2018). Employers expect that by 2022, the skills needed and required to engage in most jobs will have significantly changed, in contrast to the skills needed in today's work environment. As a result, 42% of the job skills needed to successfully

participate in the workforce will change over the next 5 years (World Economic Forum, 2018).

Employers will need 54% of all current employees to be retrained with a new skill set to engage in the future technology-rich work environment. Creativity, critical thinking, collaboration, systems and data analysis, technology design and programming, flexibility, emotional intelligence, and the ability to engage in complex problem solving are skills that will be essential in the Fourth Industrial Era work environment (World Economic Forum, 2018). Additionally, employees will need to quickly adapt to change while being innovative in their approach (Brophy et al., 2008, World Economic Forum, 2018).

The fast changing landscape of technology will cause manufacturers to no longer only create products for consumers that will be reliable and cost less (Hagel, Seely-Brown, Kulasooriya, Giffi, & Chen, 2015). Simply creating a refrigerator that is efficient and cost effective will not be acceptable to consumers; rather, consumers will demand environmental consideration, technology-enhanced features, and innovations. Additionally, industry will increase use of robotics to work safely alongside humans. Innovations will require creating these products and thus requiring fewer low-paying manufacturing jobs while increasing job opportunities for programming and technology-repair employment (Hagel et al., 2015). The new manufacturing floor will consist of wearable technology that will deliver important messages, digital screens that provide real-time data for analysis and monitoring of potential problems, virtual reality tools to diagnose machine issues, and machines to self-diagnose and correct production problems (Leurent, De Boer, & Hernandez-Diaz, 2018).

If these claims are correct, new-employee training will shift significantly, accompanied by retraining of current employees, and possible reeducation of current employees into new academic fields (World Economic Forum, 2018). The business community may be unable to address these new challenges on their own (World Economic Forum, 2018). Schools will need to change their structure in order to keep pace with the Fourth Industrial Revolution and encourage student be solution creators who are also socially conscious (Doucet, et al., 2018). Clearly, schools and the education system must play an essential role in preparing students who have the skill set needed to be successful in this newly defined workforce (Brophy et al., 2008; World Economic Forum, 2018). With this challenge in full view, the public educational system in the United States must evaluate its current practice and structure to determine if students leaving their schools possess the skills needed to engage in this rapidly changing industrial era (Doucet et al., 2018; World Economic Forum, 2018). The demand for employers to retrain nearly half of their workforce suggests that the educational system is not properly preparing students for the world of work they will enter.

The changing work environment students will enter in the near future will not be solely defined by new work skills to effectively manage technology. They will be required to actively engage people and the world around them to contribute meaningfully to their communities, solve complex problems, and meet their civic responsibilities (Berman, Chaffee, & Sarmiento, 2018). Students will need to engage with others with mutual respect, a willingness to explore new ideas, and collaboration through open dialogue, seeking to make a positive difference in the world. The ability and responsibility of students to meet their civic responsibilities is as important as obtaining

the skills and knowledge to engage in the Fourth Industrial Revolution. Although schools will need to engage in technology and job-skill development, they will also need to incorporate the social and emotional skills necessary for students to navigate their civic lives (Berman et al., 2018).

Despite the immediate and necessary demand for skills to engage in the Fourth Industrial Revolution, K–12 schools continue to be structured to develop responsible employees of a former industrial era that no longer is relevant to students and their future employment (Koh, Chai, Wong, & Hong, 2015). Schools continue to operate largely as repositories of knowledge to be bestowed upon students (Papert, 1993a). Traditional education sees intelligence as intrinsic, with minimal emphasis on development of the technological or civic skills needed to engage in the world as it has become. Too few schools are teaching students how to engage in complex problem solving or how best to improve their communities. Although it is essential that students continue to be able to read, write, and gain mathematical skills, school must also foster critical thinking, analysis of information, problem solving, learner-centered activities, and collaboration/communication with other students (Collins & Halverson, 2018). Traditional schooling establishes linear expectations for learning and systematically promotes students, once those expectations or requirements are completed.

This linear model of education is particularly evident in the traditional middle school classroom environment. For example, middle school classrooms, compared to elementary classrooms, are often less cognitively demanding, more formal in their structure, focused intensely on assessment and standardized testing, with little opportunity for student choice or decision making (Eccles & Midgley, 1989; Meece,

2003). However, as students enter middle school, their ability and desire to engage content in a cognitively rigorous manner through a real-world context increases (Brooks, 2014; Eccles & Roeser, 2011). Specifically, middle school students desire to engage in decision-making and gain autonomy in what they are learning, how they are learning, and the construction of their learning environment (Eccles et al., 1993). Despite this desire, many middle school classrooms continue to provide instruction centered on providing fact-based education, lectures, and passive work, absent of critical thinking, collaboration, and higher order skill development (Brooks, 2014; Eccles & Roeser, 2011; Larson, 2000). Middle school students exhibit a decreased lack of motivation, boredom, and a decline in academic performance as a result of the mismatch between their developmental abilities and the learning environment of a traditional middle school classroom (Eccles et al., 1993; Larson, 2000). However, the decrease in student motivation in the middle school classroom can be avoided by providing an appropriate, real-world, project based, autonomous, and properly matched learning environment (Eccles & Roeser, 2011).

The traditional linear model of education is failing students by not providing the innovative learning environments needed to acquire the technological, work, socioemotional, and civic skills necessary for the changing world students will enter. As students enter their future careers, they will be required to identify intricate problems, understand their complexity, use technology and data to make decisions, interact and empathize with the people these issues affect, and create positive change, all while collaborating and developing multiple solutions (World Economic Forum, 2018). Schools

will need to be flexible enough to allow each student to develop their own unique set of skills necessary to engage in the rapidly changing global market (Doucet et al., 2018).

Some schools have begun to investigate instructional practices that develop skills such as critical thinking, collaboration, innovation, complex problem solving, empathy, and the use of technology to amplify learning (Davis & Littlejohn, 2017). In some cases, the introduction of new instructional technology has led schools to reevaluate their industrial model of education and move toward more innovative learning methods (MacDonald & Hursh, 2006). The goal for instructional redesign should be preparing students to enter society equipped with the ability and confidence to use their intelligence and creativity. Students should be encouraged to look for new ways to think, experiment, and learn (MacDonald & Hursh, 2006).

The need for instructional redesign requires schools to move away from a lecture-based education and requires more hands-on and experimental instruction and learning (Kwek, 2011). These experiences allow students to learn by identify problems, to understand various contextual issues and others' needs and points of view, and to develop of plausible solutions to effect positive change (Koh et al., 2015). *Design thinking* is one innovative pedagogical approach that may provide a learning environment for students to gain the skills necessary to engage in the Fourth Industrial Revolution. Design thinking is simply a human-centered process that is action oriented and requires participants to be mindful of others' needs (Brown, 2009; Carroll, 2014). Additionally, participants often engage in hands-on projects that promote problem solving, empathy and perspective building, and action to improve the lives of those around them (Carroll et al., 2010). Design thinking entails specific steps including empathy, define, ideate, prototype, and

test (Hasso Plattner Institute of Design, 2017). Design thinking provides a pedagogical approach that allows students to engage with difficult and challenging problems while providing multiple viable solutions (Carroll et al., 2010). Design thinking purposefully aims to create a socially responsible mindset and attempts to specifically address the needs of others (Koh et al., 2015). Specifically, students can develop the ability to see beyond their own immediate concerns, develop empathy for others, and impact the local or global around them in a positive manner. Those who engage in design thinking are seen as actors who can make a difference in the world around them (Leinonen & Durall, 2014). Given the potential of design thinking to help people develop skills necessary to engage in the work and civic realms of the Fourth Industrial Revolution, this study examined how an educator enacted a design-thinking approach to instruction in a seventh-grade technology-education classroom.

The research and scholarship examining the possible transformational effects of design thinking on traditional pedagogy in the classroom is in its infancy. Because the exploration and implementation of design thinking is still emerging, the development of a mature culture of instruction and best practices in the K–12 educational setting is lacking (Davis & Littlejohn, 2017). As a result, some ambiguity exists around pedagogy, theory, and the implementation of design thinking. Organizations supportive of design thinking consistently review and revise their definitions and implementation models. Although some organizations have begun to narrow and formalize a cohesive structure, a clear definition and defined practice in educational settings is lacking. Additionally, a dearth of empirical studies evaluate and document the potential benefits of design thinking in practice (Koh et al., 2015; Davis & Littlejohn, 2017). Little research has examined best-

practice instructional strategies in design thinking, successful approaches for inclusion of core content using design thinking, and specific examples of design-thinking implementation at various grade levels. Questions remain about barriers teacher may face when attempting to implement design-thinking instruction. What are the supportive administrative and supervisory roles of principals and curriculum directors in bolstering successful classroom implementation? What classroom and curricular structures should be put into place to fully support students and teachers in successfully engaging content in this manner? Most importantly, no clear understanding exists of the experiences of students and how design-thinking instruction may benefit them.

To begin to answer these questions, a need persists for a wide array of empirical research on design thinking in the K–12 classroom. This study provides empirical evidence to add to the limited body of scholarship on design thinking in K–12 educational environments. In this study, I examined the practice of design thinking in a K–12 setting to better understand its benefits and limitations. Additionally, I explored the core elements associated with design thinking and the possible benefits or barriers to design-thinking instruction. The following research questions guided this study.

Research Questions

1. How does one technology-education teacher employ a design-thinking approach in a seventh-grade technology-education course?
2. How are the core elements of design thinking present in one seventh-grade teacher's unit on student-designed race cars?
3. What are the perceived and observed benefits and limitations of one teacher's efforts to engage students in design thinking?

Research Purpose

Design thinking is well positioned to develop future-ready thinking proficiencies, problem-solving skills, and communication abilities needed to be engage in a workforce environment that is quickly and consistently changing (Davis & Littlejohn, 2017). Design thinking is useful in industry and other professions (Anderson, 2012; Koh et al., 2015). Using a simple three-step process of inspiration, ideation, and implementation is an effective approach to develop new products in the business community (Brown, 2009). The use of design thinking in schools of management and innovation is taking root as well (Dunne & Martin, 2006). Increasing acceptance and success in business, industry, and, most recently, education, have produced various models and variations of design thinking. However, in the scholarship is an absence of a standard or commonly agreed theoretical framework that has been supported and tested through empirical research (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013). The lack of a standard definition and model of design thinking has created a much needed space for further investigation, especially in K–12 scholarship.

Much of the scholarship on design thinking in K–12 settings have been theoretical in nature, and little empirical data exists on the instructional practices and use of design thinking with students (Davis & Littlejohn, 2017; Mentzer, Becker, & Sutton, 2015). The limited empirical research that does exist falls short of providing compelling evidence to support and generate education policy and practice at the national level. A clear lack of knowledge relates to design thinking and curricular structure, professional learning communities on this topic, best practices, and how to support teacher growth and implementation (Davis & Littlejohn, 2017).

To better understand the potential of design thinking to promote critical skill development among students, researchers must provide further empirical studies in the K–12 environment. Studies must provide evidence of the best practices for developing design-thinking curriculum, a clear instructional framework for the successful delivery of lessons, and discussion around the possible barriers and benefits of using design thinking in a classroom. In this study, I provide a case study in a seventh-grade technology-education classroom. This project generated empirical evidence of teacher practices, lesson structure and implementation, teacher and student perspectives of teaching and learning, and outcomes. Specifically, this study provided scholarship on the possible benefits of design thinking in a middle school classroom. In this study, I examined findings surrounding the creation of a classroom environment better suited for middle school students. Additionally, I examined how design thinking may create skills in middle school students that will benefit them as they matriculate through high school and into future endeavors. Most importantly, research such as this is necessary to begin to address the lack of empirical evidence and provide K–12 institutions the necessary support to evaluate the possible benefits for students. Completion of an comprehensive case study focused on the use of design thinking is an appropriate approach to further develop the empirical scholarship examined in this study.

Additional research is needed on design thinking to determine best practices, effective ways to integrate the approach into core curriculum, how to adequately assess student learning during design-thinking projects, and how to create and develop classroom cultures that develop risk-taking, collaboration, and innovation (Carroll et al., 2010). Specifically, this study focused on three distinct areas. First, I examined the actual

implementation of design thinking in the classroom setting. Providing a detailed account of implementation provides educators with a clear picture of one example and allows them to begin to relate this information to their own learning environments. This case study adds to current examples in the literature by comparing and contrasting with the few important portrayals available. Second, I examined the degree to which the core tenets associated with design thinking were evidenced in the case. In other words, to what degree are elements such as human-centered design, empathy, critical thinking, problem solving, and collaboration present in the unit of instruction being analyzed? (Carroll et al., 2010). Further analysis focused on how and which aspects of instruction led to the observed results. Finally, I explored the possible benefits and barriers to design thinking. Resultant findings will further assist educators in the proper and effective implementation of design thinking in their schools.

Rationale

Design thinking provides a promising framework to effectively integrate a pedagogical shift from a fact-based traditional classroom to one that is student-centered and allows for skill development in critical thinking and collaboration (Burdick & Willis, 2011). Additionally, the use of design thinking supports an iterative problem-solving process that is well suited to preparing students to engage with ill-defined and complex issues. The hypothesis testing and creative thinking present in the design-thinking process can assist in developing the skills needed for a future-ready student. As an instructional approach, the use of design thinking is well suited to engage in complex problem solving and developing the skill knowledge necessary for students to perform as citizens locally and globally (Koh et al., 2015).

As previously stated, educators must develop new instructional practices resulting in students being provided the opportunity to develop the necessary work and civic skills to interact with a complex, ill-defined, and dynamic global society. Educational systems need to move toward a pedagogical approach that equips students to address these social and economic realities (Noweski et al., 2012). Despite the increased call for educational reform, including the use of design-thinking skills, schools have been slow to move from a theoretical discussion about a design-based teaching and learning pedagogical experiment to a practical and established practice (Davis & Littlejohn, 2017). This study has the potential to provide the necessary empirical evidence to encourage schools and teachers to formalize desperately needed change. Specifically, this study provides an example of the use of design thinking in a K–12 classroom. As a result, educators and administrators will be able to review successful practices, pedagogical strategies, conditions for success as well as benefits and barriers to implementation. Additionally, I sought to provide evidence of the creation of a teaching environment that allows students to gain skills such as communication, collaboration, critical thinking, and other future-ready skills.

Overview of the Study

The purpose of this study was to examine the use of design thinking in one classroom setting to document the use of design thinking as an innovative pedagogical approach. I examined the degree to which the core tenets of design thinking were evidenced in a design unit, the practices and experiences of one teacher using design thinking as an instructional practice, student experiences with design thinking, and

possible barriers and limitations to using design-thinking instructional strategies while delivering content.

This qualitative case study took place in a private residential school located in a large mid-Atlantic state. The study took place in a middle school technology-education classroom comprised of one seventh-grade technology-education teacher and the students in the instructor's 1st-period class. The unit took place over a 6-week period during 9 instructional periods. The unit of instruction observed centered on the design and creation of aerodynamic wooden race cars using design thinking as an instructional strategy and process for construction. The study results provide a full and comprehensive description of the design-thinking unit, as enacted in a seventh-grade technology-education classroom, reporting on the presence or absence of critical elements of design thinking during classroom instruction, examining the experience of the teacher and students in a classroom using design thinking, and analyzing the possible barriers and benefits of engaging in design thinking in classroom instruction.

The study included classroom observations, audio recordings of the classroom instruction, field notes of classroom instruction, and the collection and review of artifacts. I conducted two semi-structured interviews, no longer than 1 hour in length, with the teacher (as in Seidman, 2013). I interviewed the middle school technology teacher at the beginning and end of the unit of study to understand the teacher's pedagogical approach, purpose of the lessons, and intended outcomes, and to gain their personal viewpoints and insights as they relate to use of design thinking in a K–12 classroom. I interviewed students individually during the middle and at the conclusion of the unit for no longer than 30 minutes. Student interviews focused on their personal experiences, understanding

of design thinking, experiences related to the project, and insights into this pedagogical approach. I audio recorded and transcribed the teacher and student interviews.

While observing the classroom lessons, I took detailed field notes. Additionally, I asked the teacher to provide any instructional resources and student artifacts relevant to instruction and classwork during the race car unit using design thinking (e.g., PowerPoint presentations, assessments, activity worksheets, lesson plans, study guides, and pictures of student work). To analyze the resultant data, I read through the data corpus multiple times while engaging in open coding to identify collective themes. I examined these themes to determine if I could combine them or include them in larger topics. Additionally, I used deductive coding to determine the presence or absence of the stages of the design-thinking process. I present the main topics and stages of design thinking in the findings, supported by the use of direct quotations from participant interviews or classroom observations.

Definitions

Here, I provide definitions of terms that are key to this study. First, I provide a common definition of design thinking for this study. Next, I identify and explain the five stages of design thinking. Essential terminology associated with the fourth industrial revolution will be defined. Finally, I will define terminology essential to the theoretical and practical understanding of the terminology commonly used in design-thinking literature.

Design thinking. Design thinking is a process that employs real-world problem solving and relies on intricate skills and processes while employing specific mindsets to cultivate numerous and innovative solutions to ill-defined problems (Goldman &

Kabayadondo, 2017). Most commonly design thinking involves the creation of solutions for an end user who provides feedback to generate an iterative design process. Design thinking commonly involves the steps of empathize, define, ideate, prototype, and test.

Empathize. Empathy is a centerpiece of the design-thinking process. Empathy means developing a deep understand of another's perspective, ideas, thoughts, and viewpoints. During this stage, designers interact with end users through observation, interviews, and other first-hand means to gain insight into their needs, experiences, and feelings. The key is to place one's self in a position to best understand the other end user's perspective (Hasso Plattner Institute of Design, 2017).

Define. To define is to narrow the information gained by emphasizing stages to bring the design challenge into manageable focus. As the designer analyzes the data and information, a problem statement that can be acted upon is essential. This problem statement directly connects to the needs, thoughts, and opinions of the end user while incorporating the unique design of the designer (Hasso Plattner Institute of Design, 2017).

Ideate. During the ideation stage, exploration and creativity are critical. Designers take their problem statement and begin to brainstorm as many ideas as possible to providing solutions. Designers make no judgment on the quality of the ideas but rather the quantity and variety are needed to fully engage in the ideation stage (Hasso Plattner Institute of Design, 2017).

Prototype. Prototyping takes the ideas created from the previous stages and brings them into the physical world. This process can be conducted with rudimentary and inexpensive materials to start, which may then lead to more exact and functional

prototypes. During this stage, designers can engage with their models to acquire new ideas and gain insights for improvement. These insights lead to a deeper understanding of the needs of the end user and may develop other plausible solutions (Hasso Plattner Institute of Design, 2017).

Test. The testing stage allows the end user and others to interact with the prototype. Most often, these rudimentary or early solution prototypes allow for feedback and generation of the iterative process. The testing stage provides for cost-effective testing, which allows for a well-designed end product to be fully vetted (Hasso Plattner Institute of Design, 2017).

Fourth Industrial Revolution. The Fourth Industrial Revolution is commonly described as the reshaping of manufacturing using advanced technology, the improved use of robotics, augmented and virtual reality, mining of data and data analytics, biotechnology, and the increased ability to transform three-dimensional (3-D) images into the physical world (Baur & Wee, 2015; Sheninger & Murray, 2017).

Future ready skills. Skill such as creativity, collaboration, communication, data analysis, and critical thinking. This unique and broad skill set student will need to obtain in order to affectively engage and global and digital citizens. These ability to engage as positive change agents using these skills will be essential (Doucet et al., 2018).

Wicked problems. Real-world problems that are complex, multifaceted, and ambiguous, and are not singular in their solution, are considered wicked problems (Burdick & Willis, 2011). These types of problems often require designers to engage innovative and systematic approaches. Design thinking is an adequate approach to decipher and provide solutions to wicked problems.

Constructivism. Constructivists theory is based upon the idea that teachers have the ability to create an environment where learning occurs when students are actively involved, experiences are created, and teacher instruction and student construction of knowledge are balanced (Scheer, Noweski, & Meinel, 2012). Social interactions among the students which allows for learning and students to form new ways of thinking as essential.

Constructionism. Seymore Papert created the theory of Constructionism that is closely associated to constructivism with some key modifications. Constructionism supports the notion that as students engage in social collaboration with peers learning occurs. However, the mental and physical construction of items and the reflection on this process is essential and allows for the maximization of understanding and learning for students (Goldman & Kabayadondo, 2017). As students create and mentally think about the construction of artifacts, they create new mental frameworks that enhance and build socially constructed knowledge.

Summary

The world is moving toward a global economy and society, creating new and unknown demands on the workforce and from citizens. As a result of these changes, and the development a Fourth Industrial Revolution, employers are seeking employees with skills to meet the quickly changing environment (Brophy et al., 2008; World Economic Forum, 2018). Schools must reevaluate their current models of instruction. Despite this call for change, schools have been slow to adopt innovative and new pedagogical approaches that will provide students the necessary skills to fully engage in their future (Davis & Littlejohn, 2017). Empirical research and evidence on these innovative

pedagogical approaches may provide schools the necessary foundation to begin discussion and implementation plans to radically change instructional environments.

Design thinking is an innovative pedagogical approach that may provide students with the necessary exposure and skill acquisition required for their future (Koh et al., 2015). Despite this promising assertion, little empirical evidence accompanies a lack of consensus around the definition and best practices, and a lack of a clear framework for implementation (Davis & Littlejohn, 2017; Mentzer et al., 2015). This qualitative case study adds to the literature to begin to answer these questions and provide educators with a generalizable example for implementation.

Chapter 2

Review Of The Literature

This chapter includes a review of the literature on design thinking. As the main theoretical framework for this study, I also define and examine constructionism. From this theoretical perspective, I examine design thinking in development, definitions, key components, and theoretical models. I present the Stanford d.School Model of design as the model used in this study. Additionally, this chapter includes a wide-ranging examination of empirical research studies that focus on the use of design thinking in education. Due to the lack of scholarship on design thinking in Grades K–12, this chapter includes studies conducted in higher education classrooms and settings. Finally, in this chapter, I explore themes related to the implementation and outcomes of design thinking and educator experiences delineated in the literature.

Constructionist-Learning Theory

The theory of constructionism, in its simplest form, postulates learning is most likely to occur when people are making tangible items in a real-world setting (Dowling, 2012). These learning experiences can be characterized as solutions to real-world problems that are often forged in social-learning environments and include interactions with an end user, collaboration and exploration of solutions among peers, and iterative brainstorming and testing of solutions. It is easiest to fully understand the development of this hands-on socially constructed learning theory by reviewing the foundation of learning theories leading to constructionism.

Theories of learning generated by Dewey, Freire, Vygotsky, and Piaget offer foundational principles from which constructionism was created and established

(Goldman & Kabayadondo, 2017). Dewey asserted that all learning is social (Dowling, 2012). As students engage in a socially constructed learning environments, the use of common aspects and objects of life enhances this learning. The use of everyday examples allows students to deeply engage in content and common understandings with peers to begin to evaluate current thinking while integrating new concepts. As a result, Dewey hypothesized, students would demonstrate an increased ability and likelihood to engage in the learning process (Papert, 1993b).

Freire (1972) proposed educators should engage in conversations with students to create a consensus of thought. Having these conversations would stimulate and create the necessary awareness of reality, and thus activate learning. Additionally, Freire advocated for the use of visual aids and sketches to enhance the learning process. Vygotsky noted the importance of the social relationship to learning and focused on the language used in these learning environments (Goldman & Kabayadondo, 2017). These theorists contributed to the foundational aspects of constructionism by highlighting the importance of the social relationship to the learning environment, of collaboration and discussion among peers, and of hands-on activities and creation to amplify learning. Further, they provided a foundational basis for the work of Piaget and the social-learning theory of constructivism.

Although the above-mentioned theorists had a considerable influence on the establishment of constructionism, Piaget's theory of constructivism serves as the main foundation. Piaget theorized educators do not simply convey information and content to the learner; rather, students analyze, label, categorize, and then assimilate during the process of learning (Papert, 1993b). Constructivists theorize that teachers have the ability

to create an environment where learning occurs when students are actively involved, experiences are created, and teacher instruction and student construction of knowledge are balanced (Scheer, Noweski, & Meinel, 2012). Constructivist learning environments create rich opportunities for social interactions that, in turn, create collaborative and student-centered learning classrooms. Students are able to take the new information along with their previously held knowledge and create new understanding. This allows students the freedom to explore in a framework where the teacher serves as the facilitator of knowledge characterizes this knowledge building (Dowling, 2012). As the facilitator, the teacher becomes a guide who shepherds students through a rigorous and meaningful construction of knowledge.

As a student and colleague of Piaget, Papert supported and agreed with many of the tenets of constructivism. However, Papert sought to expand on the theory of social constructivism, leading to the development of the theory of constructionism (Papert, 1993a, 1993b). Papert theorized and supported that students learn as they engage in social collaboration with peers. However, further, as students engage in the mental and physical construction of items and reflect on this process, optimal and increased learning for students occurs (Goldman & Kabayadondo, 2017).

Constructionism focuses on the influence of mental construction that occurs during the creation of real-world artifacts (Papert, 1993b). As students create and mentally think about the construction of artifacts, they create new mental frameworks that enhance and build socially constructed knowledge. Constructionism stands boldly in opposition to the popular and still often used instructionism approach to learning. Instructionism seeks to engage students in learning through content and facts that are

directly delivered where the teacher is positioned as the keeper of knowledge (Papert, 1993b). According to instructionism, for student learning to increase, the quality of teaching simply needs to improve. Papert, while valuing instruction, described teachers using constructionism as facilitators of knowledge who should effectively limit their instruction to allow students to explore content and thereby optimize learning. Papert (1993a) believed the collaborative, interactive, and student-centered learning environment represented in constructivism are essential and key to learning. However, the creation and manipulation of actual physical objects during learning allows for deeper learning, understanding, and the conceptualization of ideas (Papert & Harel, 1991).

Constructionism aligns well with the practices of design thinking. Essential components of the design-thinking process include hands-on processes and the creation of prototypes, which serves as the foundational component of a constructionist learning environment. Papert proposed students engage in the learning process to learn skills necessary to seek the knowledge they require for future learning. This type of reflective and self-driven learning can create an optimal learning environment but requires the facilitation, intellectual support, and required materials provided by the teacher and school (Papert, 1993b) The collaborative learning environment, mental models of construction, hands-on creation of artifacts for learning, real-world problem solving, and social construction of knowledge are hallmarks of constructionism, providing a solid theoretical foundation for understanding and examining design thinking.

Design Thinking

To fully understand the foundational principles of design thinking, it is helpful to review the history of design and the emergence of design thinking as a pedagogical

concept. The concept and implementation of design have been present throughout human history. However, the examination of design and design thinking in research is rather new (Kimbell, 2011). As a result, at present no one clearly defined design-thinking theory or methods of practice. However, scholars have begun to provide some research surrounding the origins of design and design thinking. To fully understand the principles associated with this research, I describe the work of several theorists who provide a foundational platform for design thinking. Simon, Schön, and Cross are three theorists who have provided essential theory on which much of the practice of design thinking rests (Koh et al., 2015).

Simon, author of *The Sciences of the Artificial*, sought to elevate the practice of design to the same level as other respected academic fields (Koh et al., 2015). Simon argued that the use and study of design are meaningful; the theorist sought to encourage schools of engineering to carefully and systematically consider its value as a distinctive discipline and theory (Simon, 1996). Simon argued for the creation of a program of science that focused on the academic content of artificial constructs. The author argued that formulating a clear difference between the natural scientific domain and the construction of artificial solutions allows for the discovery of multiple alternate solutions better suited to address ill-defined problems (Lugmayr, Stockleben, Zou, Anzenhofer, & Jalonen, 2014). Simon sought to bring respect to the academic concept of design among the academic community. However, one criticism of Simon's work was dismissiveness of the professional, expert, and intellectual aspects of design. Simon strongly contended that anyone who sought to improve circumstances through the design process was able to effectively engage in design. The pursuit and enjoyment of working through the design

process was privileged by Simon as one of the most important parts of engaging in the design process (Koh et al., 2015; Simon, 1996)

Schön's work, *The Reflective Practitioner,* contrasted with Simon's work and focused on the artistic, unstable, conflict, reflection, and intuition inherent in design (Koh et al., 2015). Although dissimilar in approach, Schön demonstrated a similar goal: to establish the legitimacy of design and design theory as a respected and recognized academic discipline. Reflection-in-action is one of the most important concepts Schön contributed to the field of design. As experts engage in complex and ill-defined problems, Schön argued, they have no way to know all the aspects of the problem and what further issues may arise. The expert designer must apply the knowledge they currently possess and then be willing to acquire, inspect, and apply new information as it emerges. Schön's focus on the reflective nature of engaging in complex problems provides foundational structure to today's current design-thinking theory (Koh et al., 2015).

Cross (2007) continued to expand on the theoretical underpinnings and importance of design in *Designerly Ways of Knowing.* Similar to Simon, Cross aimed to establish design as a recognized academic area, equal to the sciences, while being integrated into the general education of all students. Further, Cross emphasized the influences design theory and education could have on solving ill-defined problems and developing the communication skills of students. All three of these theorists provided essential ideas and theoretical constructs of design thinking, such as examination of ill-defined real-world problems, openness to multiple solutions, collaboration and communication skills, and reflection on the process. Although each of these theorists attempted to add some legitimacy and structure to the field of design and design thinking,

no common agreed-upon established standard, academic practice, or manner in which design thinking is implemented exists, especially in the academic setting (Koh et al.; 2015).

Although design theories have provided a foundation for the discussion and use of design thinking in areas such as business and education, considerable expansion and exploration of design thinking in these fields has only occurred since the early 2000s (Coakley, Roberto, & Segovis, 2014). Despite a lack of cohesion, a review of design-thinking models present in the literature reveals some similar principles and definitions. Commonly, design thinking indicates a process that employs real-world problem solving and relies on intricate skills and processes while employing specific mindsets to cultivate numerous and innovative solutions to ill-defined problems (Goldman & Kabayadondo, 2017). Participants create new objects, concepts, stories, and methods. Further, design thinking is a method that effectively addresses and provides innovative solutions for "wicked problems" (Buchanan, 1992). Wicked problems are ill-defined issues that have no single correct answer but are complex, with multiple and varied solutions. These problems consistently change and require people to think in new and different ways to develop possible solutions (Leinonen & Durall, 2014).

Although the definition of design thinking is somewhat broad, several key facets are foundational to the mindset and learning involved in this process (Carroll et al., 2010). First, design thinking is a human-centered process that focuses on engaging in real-world problem-solving. The end user provides the inspiration, emotion, perceptions, and ideas that are essential to the design process (Adams & Nash, 2016). Second, the designer must empathize with the end user to properly engage in design thinking.

Empathy provides the feelings, thoughts, and attitudes that engage the human-centered aspect of design thinking and is the main source that drives innovation (Carroll et al., 2010; Goldman & Kabayadondo, 2017). Designers gain empathy through observation and communication with the end user to fully understand their implicit and explicit needs. As noted earlier, empathy for the end user provides the energy that drives the designer to create and provide a viable solution for the end user. Third, the culture of prototyping emphasizes the flexibility, failing forward, making changes from feedback, and the creation and improvement of multiple possible solutions. This mindset necessitates forward thinking and demonstrates a strong proclivity to quickly pivot direction to test new ideas. Fourth is the concept of visualization and the creation of tangible artifacts. Creation of a tangible model allows the designer to produce and imagine perspectives not once known or understood prior. Additionally, the creation of artifacts allows for evaluation and feedback from the end user. Bias toward action is the fifth key aspect of design thinking. Designers are seen as active participants. By engaging in this process, they can make a difference (Leinonen & Durall, 2014). The focus is on the creation of relevant and meaningful solutions that will positively affect and benefit the end user. This is most evident through action-oriented aspects of prototyping and testing, which leads to a more suitable solution (Carroll et al., 2010). Last, the concept of radical collaboration, where teams of people engage in communication and idea sharing, creates diverse and innovative solutions. A keen awareness of group dynamics and the ability to address issues as they arise are essential to success. Although each of these aspects of design thinking is individually essential and foundational, they must be brought together to effectively engage in this process.

Design-Thinking Models

The growing popularity of design thinking as an innovative tool has led to the creation of several theoretical models. Whereas most models share some similar aspects, they do not equally engage participants in the same process, rigor, and ability to test or evaluate the feasibility of their design solutions (Brophy et al., 2018). In this section, I present an overview of several design-thinking models present in the literature. CEO of IDEO Brown described a model of design thinking used in their innovative design firm. The three components of Brown's (2009) design-thinking model, shown in Figure 1, are inspiration, ideation, and implementation.

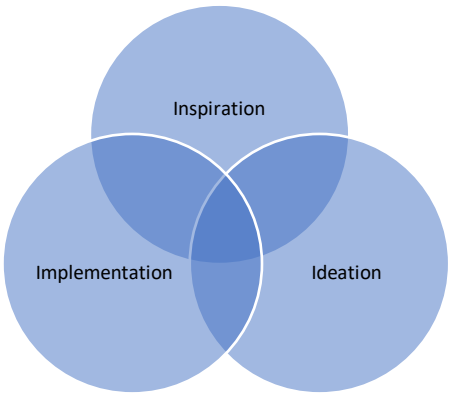

Figure 1. Design thinking model created by Tim Brown.
Note. From *Youth Voices: Youth-Centered Design Thinking,* by R. Long, n.d., retrieved October 14, 2018, from https://slideplayer.com/slide/12145676/

The design-thinking process in this model can be understood as three overlapping spaces that interact rather than taking place as linear and orderly steps (Brown & Watt, 2010). Inspiration requires the designer to focus on identifying the problem, which provides the needed direction and purpose to solve the issue. Ideation provides a space for the generation and testing of ideas. Finally, implementation carries the idea from a conceptual space to the real world. In this stage, designers bring a solution to life and

apply it to the issue presented. Brown explained the process is iterative in nature while allowing for creativity, exploration, and open-mindedness in the creation of multiple and innovative solutions. Although widely accepted as an authentic design-thinking model, this model is not well based in empirical research (Johansson-Sköldberg et al., 2013).

Brown's model often aligns with design thinking used to innovate industry and business. Recent researchers on business education in the college setting employed Brown's model. Benson and Dresdow (2015) noted the use of Brown's three-step process as a model of design thinking in their research, noted in Figure 2. College students engaged in a design challenge in a business-education course. Students addressed this challenge by engaging in an inspiration space during Phase 1 when they were tasked with developing empathy for their end user. Phase 2 required students to ideate possible solutions focused on ethical and social issues, stockholders, and manufacturing logistics. Implementation of Phase 3 engaged students in 3D sketching and full-scale prototypes. Students also returned to the inspiration phase to consider the social impact and environment. A return to the previous stages is common practice when engaging in design-thinking challenges.

Also in the literature are models of design thinking that are more commonly implemented in an academic setting. Many of these models expand on the concepts and stages of design thinking to provide a more scaffolded and defined description of the requirements for each stage. For example, Lim, Lim-Ratnam, and Atencio (2013) implemented a model of design thinking for their study of design and technology in a secondary-level school in Singapore. This model (see Figure 3) uses five stages of the design-thinking process in which students understand a situation, research the problem

through data collection, ideate solutions, develop a prototype, and test or realize the possible strengths and weakness. The model used in the Lim et al. (2013) study provides a clear representation of an active and cyclical interaction among the stages in which students engage to design a possible solution. The collection of information and data during each stage is essential and more pronounced in this model.

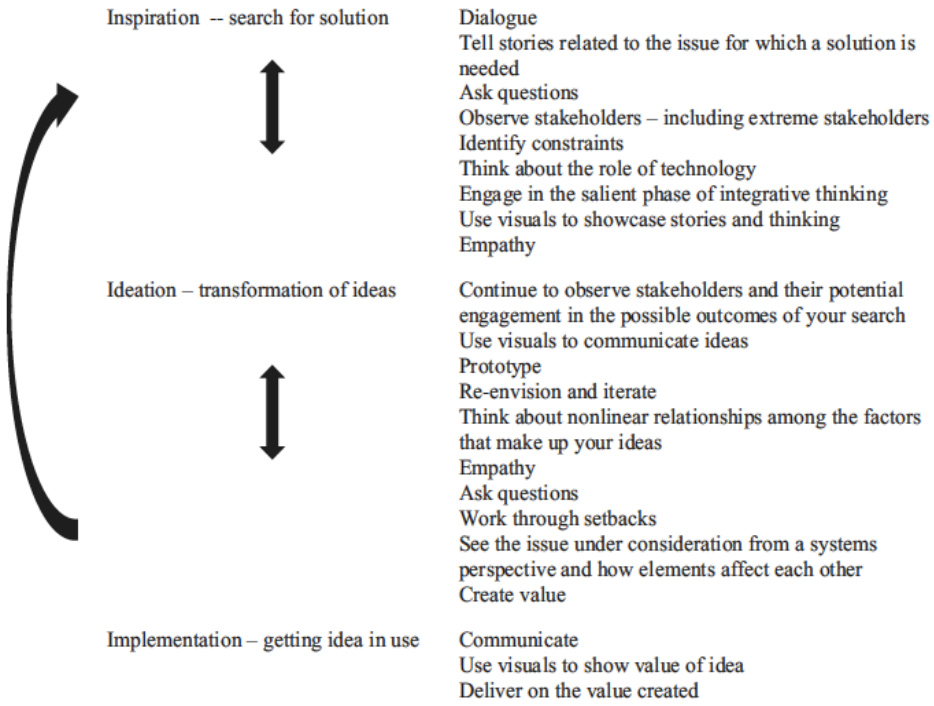

Figure 2. Brown model of design thinking used in research completed by Benson and Dresdow.
Note. From "Design for Thinking: Engagement in an Innovation Project," by J. Benson & S. Dresdow, 2015, *Decision Sciences Journal of Innovative Education, 13*(3), p. 382. https://doi.org/10.1111/dsji.12069

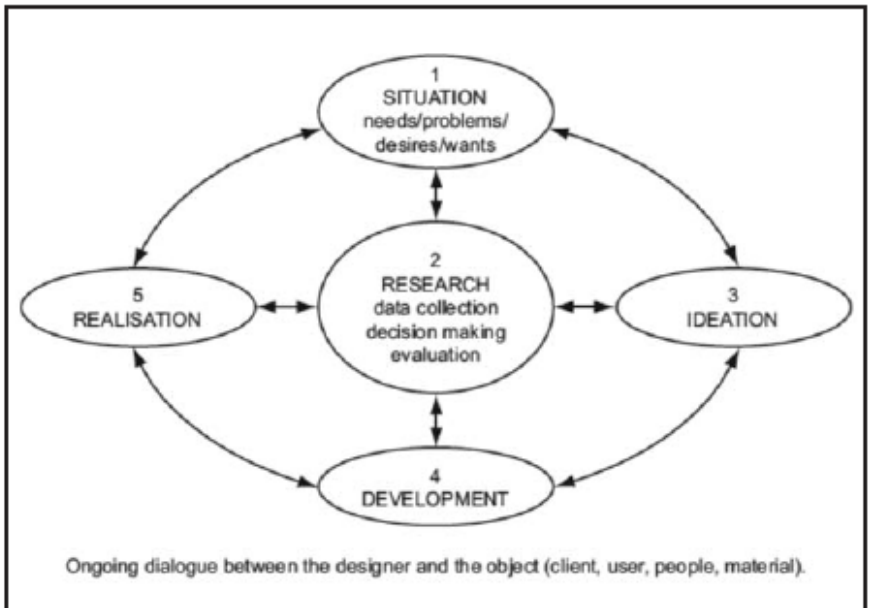

Figure 3. Design thinking model used by Lim et. al. (2013) for research on design and technology.
Note. From "Understanding the Processes Behind Student Designing: Cases From Singapore," by S. S. H. Lim, C. Lim-Ratnam, & M. Atencio, 2013, *Design and Technology Education, 18*(1), p. 21. available from ERIC database. (EJ1007137)

The Stanford Design School created a model of design thinking that focuses on innovation, consumer demands, and problem solving using creativity and engineering (Lugmayr et al., 2014). The Stanford d.School model of design thinking comprises several stages that represent essential concepts in the design-thinking process . The model, noted in Figure 4, consists of five stages: empathize, define, ideate, prototype, and test (Stanford d.School, n.d.).

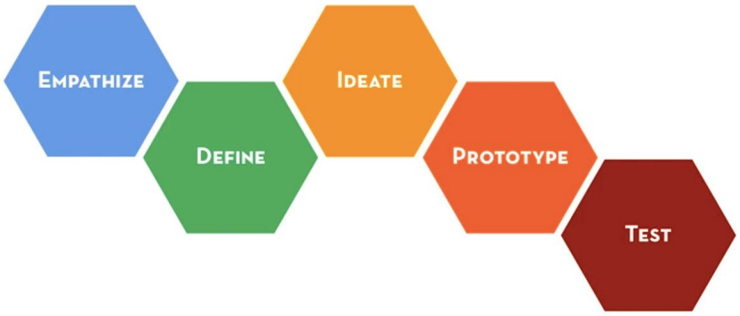

Figure 4. Stanford Design School model of design thinking.
Note. From *An Educator's Guide to Design Thinking,* by Stanford d.School, n.d., retrieved from https://dschool-old.stanford.edu/sandbox/groups/k12/wiki/14340/attachments/e55cd/teacher%20takeaway.pdf?sessionID=26dcbd4186155bfea2dd26fef789ff1f2ca793f3

Empathizing is the ability to understand and discover the needs of the end user. Designers can gain empathy through interviewing techniques, observation, and immersion into the setting. The define stage requires the designer to narrow the information received to understand the needs of the end user. Student designers can use various techniques during this stage to help organize the information compiled during the empathy stage to seek common themes on which to build. This stage allows the designer to focus on the main problem or issue the end user is presenting. The next stage, ideate, involves the process of imagining possible solutions to the previously identified problem through brainstorming. Students engage in a process in which all and any ideas are heard, respected, and recorded. This stage allows for the expansion of the design process to include any and all solutions with no judgment or evaluation of their worth.

Once all ideas are collected student designers must begin to narrow once again and decide on an idea to prototype. Prototyping allows for the iterative creation of possible solutions through sketching or the physical building of models. Students may also prototype several models quickly and choose which one to more fully develop.

Feedback from peers and collaboration while narrowing toward a possible solution are important during this phase.

The test stage is operationalized by the testing and evaluation of the prototypes created by the designer or end user. The end user or others testing the prototyped solution are able to provide feedback to the designer who is able to improve and retool their original design. Similar to other design-thinking models, this process is not linear and invites iteration as part of the process (Stanford d.School, n.d.).

Empirical Research on Design Thinking

Although the models outlined in the previous section have been used in industry, engineering, and higher education, little empirical evidence exists of the consistent and pervasive use of design thinking in K–12 schools (Anderson, 2012). In the following sections, I review the current research surrounding the use of design thinking in education. To develop a full understanding of the scholarship on design thinking in education, the review of the current empirical literature includes university studies as well as K–12 studies on the use of design thinking during instruction.

Use of Design Thinking in the University Classroom

The use of design thinking in college courses as an instructional strategy has been documented in several studies. Lee and Benza (2015) studied a graduate-level marketing class in which the instructor challenged students to apply empathetic design thinking toward a targeted marketing audience. The instructor asked students to create an innovative and new product while developing a branding strategy. Although the main project focused on branding, the goal of using design thinking during instruction was to

develop the empathetic skills of students to better understand clients and their needs and objectives.

The researchers surveyed students mid-semester to gauge their thoughts on the use of design thinking as an instructional strategy. When asked questions about the benefits of design thinking, students reported an increased ability to innovate and think creatively by using the steps associated with design thinking. Further, students reported collaboration among peers was the most beneficial aspect of design thinking related to this brand-marketing activity. Students also reported a strong connection between what they were learning in the course and how this could relate to skills needed in their future employment. Although the results support design thinking to develop skills, the study would have been well served to follow up with a survey after the course concluded, to further support and confirm the findings.

Lee and Benza (2015) also examined the relationship of the physical set up of the classroom to design-thinking instruction. Findings showed the optimal design-thinking classroom should be equipped with flexible seating, adaptable work areas, and enough space to allow students to create. Supplies needed to engage in the projects can range from complex to simple and could include power and hand tools, glue, cardboard, and tape, as students build appropriate prototypes. The creation of a well-designed and supply-rich learning environment is necessary for high student learning and engagement (Lee & Benza, 2015).

Benson and Dresdow (2015) studied the application of design thinking in an undergraduate, decision-making business course. Students enrolled in the course had completed a prerequisite class focused on organizational behavior and had baseline

knowledge of decision making. the instructor presented students with a design challenge to develop a new product with an organizational-design structure. Students worked in teams of seven to nine students, provided with instruction about design thinking and decision making prior to engaging in the design project. In Phase 1 of the project, students engaged in analogous empathy of the customer and evaluated the feasibility of the marketplace. Phase 2 involved the ideation stage in which students considered social, legal, and ethical issues of manufacturing their product and understanding the needs of stockholders. In Phase 3, students implemented their plans by refining their product and creating 3D sketches and prototypes.

Students wrote individual reflection papers about this design project, which the researchers evaluated for themes surrounding design thinking. The reflection papers indicated 77% of the students identified design thinking as an effective way to engage in learning (Benson & Dresdow, 2015). Further, empathy (81%), integrative thinking (86%), collaboration (90%), optimism (70%), and experimentation (83%) were all present in significant amounts in the student-reflection papers. The researchers provided a survey to the students. Results indicated students reported gaining more skills in critical thinking, creativity, and the ability to innovate, which are skills not only associated with design-thinking methods but also highly desired by employers. Although the study did reveal positive outcomes of design thinking, questions remain about how these learned skills would be transferable to future collegiate courses or the workplace.

Dowling (2012) reported similar results from a study working with 2nd-year interior-design students in a university setting. An interior-design-technology class received a hands-on design challenge to create a closed-loop system focused on issues of

sustainability and interior-design principles. Students created a schematic design using sketches and cardboard materials as individuals. Students then gathered in collaborative groups to review the designs, provide feedback, and make revisions. A postclass survey of the students showed that 78% thought the design-thinking hands-on project helped them devote course-specific content to long-term memory. Additionally, students reported a deeper understanding of course concepts along with enjoying kinesthetic creation, experimentation of multiple solutions, and innovation aspects of the design-thinking experience.

Although many studies completed in a university setting focused on the use of design thinking with traditional instructional practices, Lockard and Hargis (2017) completed a study in a collegiate environmental and interior-design course that fully embraced a student-driven classroom, based on the use of a design-thinking principles. The qualitative study included two male and five female students given autonomy to shape the direction of the course and complete the design-thinking challenge, drawing on the Freire pedagogy-of-oppression approach. Consequently, students had autonomy with appropriate justification to choose working groups, provide input and direction to complete projects, dictate appropriate project sites, and solve any conflict among groups or individuals. The primary goal of the study was to allow students to innovate and direct their own learning while using design thinking to brainstorm, innovate, prototype, test, gain feedback, and reiterate.

Through observations, student interviews, and questionnaires, the researchers found that the teams worked collaboratively and developed a sense of ownership for their project (Lockard & Hargis, 2017). However, students had difficulty engaging in conflict

resolution and often looked to the instructor to solve issues. When the instructor would not acquiesce, students demonstrated increase skill development in communication, resolving conflict, and making decisions. Although this study demonstrated some positive results, several aspects may be barriers to successful replication. First, the instructor had a previously established relationship with several participating students, which promoted an important level of trust. The absence of this trust could lead to dissimilar results. Additionally, students engaged in this study were older than the average college student. The possibility exists that greater maturity and life experiences may have contributed to students' ability to negotiate a student-driven classroom environment.

Additional research at the university level examined the implementation of design-thinking instruction outside the traditional collegiate classroom. Tsai (2015) completed a quasiexperimental study, randomly selecting several online semester classes providing instruction in learning Microsoft Excel. The 153 undergraduate students were chosen based on their enrollment in three sections of the course. Each section was assigned a different intervention that included design thinking and coregulated learning (CRL) in a blended-learning format, CRL only in a blended-learning format, and traditional teaching in a blended-learning format. Tsai described CRL as self-regulated learning with the influence and support of peers and instructors during the learning process.

All students completed a technology aptitude pretest to ascertain a baseline of computer skills. During the semester, students worked in their groups to learn content and complete projects. The end-of-course skill results demonstrated a positive significant difference ($p < .05$) between the skill level of the design thinking and CRL group (71.22)

and the CRL only group (53.07). The researchers concluded that the design-thinking intervention contributed to the increased student development and mastery of the content. Further data analysis showed that the design thinking and CRL treatment group achieved statistically significant higher grades than the other two groups. Although these results support design thinking in a blended online class, consideration must be given to the possibility that students may have possessed differing levels of computer skills. Further, peer influence and the quality of the instructor of each section may have impacted the results (Tsai, 2015).

Coakley et al. (2014) conducted a study on a 3-day intensive experiential learning program for all freshmen students with an engineering major. The 3-day program had four main objectives. First, students would apply the design-thinking process to engage with ill-defined and complex problems and develop plausible solutions. Second, students would develop skills around brainstorming, constructive conflict, and debate with their fellow team members. Third, each student would discover and understand their learning style and how to work with others who differ in this manner. Fourth, students would begin to understand how to communicate with others in a clear and succinct manner. Day 1 of the intensive program provided instruction on essential knowledge that would be necessary for the completion of the design challenge. The faculty person instructed students on the basic tenets of design thinking, design-project descriptions, observation skills, and brainstorming techniques. On Day 2, students conducted field research at a mall movie theater and returned to begin brainstorming possible solutions and prototyping. Day 3 involved enhancements and revision to the prototypes with a presentation of the final product.

Student survey results showed a 75% satisfaction rate with the program (Coakley et al., 2014). Specifically, students stated they learned more from this intensive program than they would in a regular classroom. However, the researchers noted it was difficult for many students to trust the process of design thinking. Many students looked for quick answers and demonstrated premature solution bias. Additionally, findings showed students exhibited difficulty brainstorming, despite being given specific training on this skill. This study provides some additional support for the use of design thinking and benefits for learning content through this pedagogical practice. However, results can be of limited transferability, given that the instruction took place outside the normal classroom setting.

Another study on the use of design thinking outside the traditional classroom setting involved a qualitative case study on a design-thinking seminar completed with 11 international collegiate students (Lugmayr et al., 2014). The authors studied the use of design thinking over a period of 5 seminar sessions, each focused on the design-thinking principles of empathy, define, ideate, prototype, and test. The instructor assigned participants to teams and each completed a different business-management task. The researchers analyzed the learning journals of participants and found that students understood and engaged quickly with design thinking. Participants also cited the benefits of divergent groupings to engage in ideation and creation of innovative solutions. Also, the data revealed that participants developed improved collaboration skills. Despite the increased collaboration and powerful ideation, participants found it difficult to narrow and focus on one particular solution when presented with many innovative ideas.

Collectively, studies at the university level demonstrate a wide range of approaches, objectives, participants, and outcomes. However, the authors consistently reported that collegiate students view the use of and engagement in design thinking as useful, impactful, and positive (Coakley et al., 2014; Tsai (2015). Further, collegiate students engage with the content of the courses in a deeper and more meaningful manner with design-thinking challenges than traditional instructional in the university classroom (Lugmayr et al., 2014). The research, while demonstrating some similarities in results, varied in focus, setting, commonality of practice, and instructional use of design thinking in a collegiate classroom. Researchers lack consensus about the best practices for promoting design thinking among collegiate students. Further, the wide-ranging levels of collegiate students, from underclassmen to doctoral students, adds to the difficulty in defining best practices and implications of this innovative teaching method.

Design Thinking in K–12 Schools

Although research on the use of design thinking in higher education is useful for gaining a larger understanding of design thinking in an academic setting and for practitioners at the collegiate level, the results of these studies may yield results that are not generalizable to K–12 teachers (Mentzer et al., 2015). A review of the current research on the use of design thinking in K–12 schools is necessary to understand the benefits, barriers, and possible best practices for instruction in this setting. The research reviewed below is organized by high school, middle school, and elementary school categories.

High School

Apedoe, Reynolds, Ellefson, and Schunn (2008) completed a study on a chemistry unit of instruction that used design thinking for instruction. The study examined 271 high school students in Grades 9 through 12 who completed the entire unit of instruction along with pretests and posttests. All students in the study received the same instructional methods and content. The instructor presented a design challenge to create a heating and cooling system in an 8-week curriculum. This instructor chose this topic so students could easily relate the problem to their everyday lives. Students received direct instruction about design thinking, innovative product design related to Dyson vacuums, and chemistry principles of the reaction and container system in heating and cooling systems. Brainstorming ideas, creating prototypes, and creating multiple iterations of the solution were key aspects of the instruction. Students completed a pretest and posttest, an adapted version of the Chemistry Concept Inventory, to measure their acquisition of chemistry content. Figure 5 represents the results of this inventory. Students exhibited a slight increase in content knowledge in all three core chemistry areas. However, the small effect size in each category could indicate that design thinking did not have the anticipated intended impact (Apedoe et al., 2008).

To consider other possible impacts of engaging students in design thinking, researchers compared 79 students who participated in the study with 59 students who did not (Apedoe et al., 2008). The students who participated in the study reported they were more likely to pursue engineering in college or participate in future design courses. These results were statistically insignificant. Second, the use of design thinking avoided learning content in isolation. Instead., students learned content in conjunction with the

project and the design-thinking process (Apedoe et al., 2008). Although this study focuses on the connection between design thinking and curricular content, the lack of teacher interviews and quantification of varying degrees of design-thinking instructional experience leaves questions unanswered.

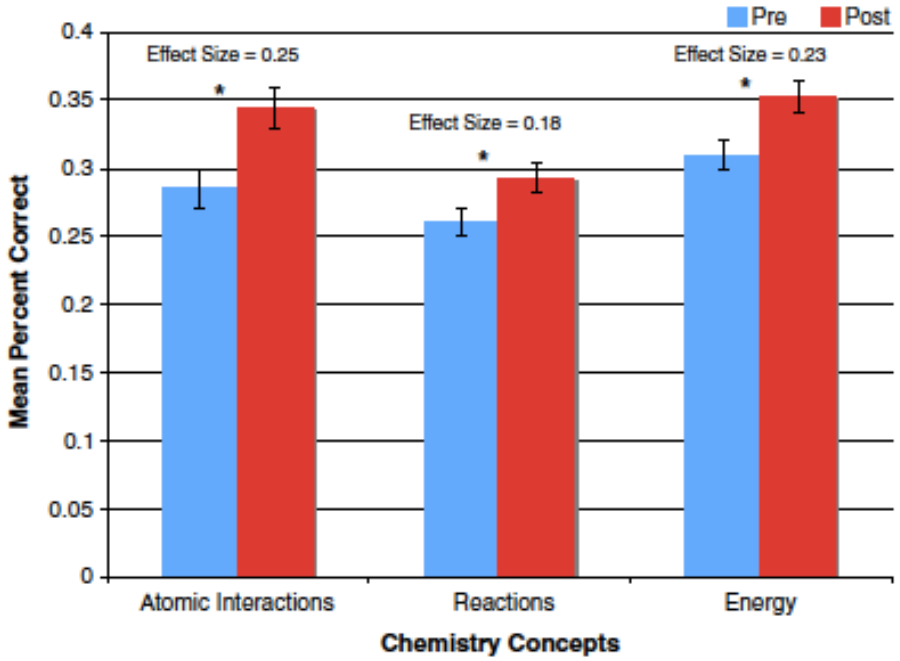

Figure 5. Chemistry Concept Inventory pretest and posttest inventory results from a study using design thinking.
Note. From "Bringing Engineering Design Into High School Science Classrooms: The Heating/Cooling Unit," by X. S. Apedoe, B. Reynolds, M. R. Ellefson, & C. D. Schunn, 2008, *Journal of Science Education and Technology, 17,* p. 462. https://doi.org/10.1007/s10956-008-9114-6

Additional researchers examined the use of design thinking with high school students outside the formal classroom setting. Kramsky (2017) examined a 3-day after-school design-thinking workshop held at a Boys and Girls Club in Los Angeles. The 17 ethnically diverse students were considered to be "at risk" due to either repeating a grade or failing a reading or mathematics course. Additionally, students were considered economically disadvantaged while also demonstrating behavioral concerns. Data accrued

using pre- and postworkshop questionnaires and student interviews. To provide students with a real-world problem, the instructor asked students to design a solution for the environmental water challenge in their community. The workshop focused on observation and sketching of the dry channel in the community. The students then brainstormed solutions and used a sticky-note activity to cluster themes. Students focused on creating a solution for reducing water usage at the youth center and ideated possible solutions. Students created 3D prototypes out of cardboard to transfer their ideas to a workable prototype.

The pre- and postworkshop questionnaires resulted in a demonstrated improvement in understanding of the environmental concepts and design thinking (Kramsky, 2017). Additionally, students were able to take the concepts from the workshop and use them to construct their 3D models related to landscape, topography directing water, and water storage. Although the study demonstrated the ability to connect content learning through the use of a design-thinking workshop, the researcher noted the results may have improved if the exposure to design thinking would have been in a more formal setting for a longer period of time. Additionally, the small-group setting of the workshop may not be possible in a formal classroom setting, further making the results of the study less transferable to traditional K–12 education settings.

One mixed-methods study in a high school setting compared the activities of design experts, high school seniors, and high school freshman. Mentzer et al. (2015) compared high school students' thinking to that of design experts when engaged in engineering courses implementing design thinking. Participating students were 29 seniors and 30 freshmen who engaged in a sequence of engineering courses during their high

school education. The researchers categorized students and teachers in the study as generalizable to the U.S. population. The design challenge provided for this study consisted of developing a playground for the local community. All participants received a written proposal for the playground, a comfortable working space, and materials needed to design and prototype. The researchers observed and video recorded all sessions for future analysis.

The study results demonstrated a significant difference between the design experts' and the high school students' processes for gathering of information and developing a clear understanding of end users (Mentzer et. al., 2015). The significant amount of time the design experts spent on idea generation compared to the high school seniors demonstrated this divergence. Information gathering, feasibility analysis, problem scoping, and decision-making were all statistically significantly different at the $p < .001$ level between the two groups. Although seniors spent more time than freshman on the project, only time devoted to idea generation and decision making were noted as being statistically significant at the $p < .05$ level between these two groups. The freshman designers also tended to focus on a single solution and engaged less in problem scoping than did the seniors and design experts (Mentzer et. al., 2015).

Study results confirmed design experts have a greater understanding of the necessary steps in creating a proper design and use the necessary stages to engage in the process (Mentzer et. al., 2015). However, although the high school students did not meet the level of expertise of the professional design participants, they were able to appropriately engage in design-like processes and activities. One possible drawback and limitation to this study is that students knew the actual design would not be built and

installed. This additional motivation may have changed the amount of time the novice designers spent on the projects.

In the Lim et al. (2013) comparative multicase study, researchers examined two 16-year-old high school students as they engaged in a design and technology course in a Singapore high school. Student design journals and audio tapes of student verbalizations as they worked on the design challenge served as data sources. Both students were well established in design and had been award winners for design contests at the school. The first student identified the need for a make-up holder after seeing a need in the student's own house. The student participants interviewed targeted users and completed research on common sizes of make-up containers. Reflection and iteration of prototypes were evident throughout the process. The second student examined the design challenge of creating a device to coil up guitar strings. The student spent an extended amount of time examining the original focus, purpose, and design of the project. The student created 46 pages of design sheets that were unorganized and messy. The student built several prototypes sketches and actual 3D models with interleafed iterations (Lim et al., 2013).

The students were afforded autonomy and agency in this course, which allowed for many design iterations and reflections on their failures for improvement (Lim et al., 2013). The students demonstrated the individual skills and ability to engage in the design-thinking process during this course. However, many students do not possess the expertise needed to engage in such a meaningful way. Students in a high school setting would most likely require a more structured and instructor-supported classroom environment (Lim et al., 2013).

Although most of the research on K–12 design thinking focuses on outcomes, connection to content, process, or engineering aspects, one study examined the use of design thinking to foster aspects of social-emotional learning. Norris (2014) completed a 14-month ethnographic study with 19 high school Latinx and African American adolescents. The purpose of the study was to examine a possible relationship between self-perception and design-tangible artifacts, what kinds of tangible artifacts might be created through the teaching of positive self-concepts, and how design thinking might inform a young woman's gender and racial identity. The session teachers were instructed quarterly with professional development on design thinking. Students also engaged in the design challenge quarterly and instructors asked them to create an ode to someone they loved. This process eventually led to them designing a 3D representation of this creation (Norris, 2014).

Results revealed that some students refused to participate and did not enjoy the course (Norris, 2014). The researcher attributed this refusal to the notion that many students had been engaged in a problematic and dysfunctional relationship, leading to an inability to create the project. The researcher noted that the conditions necessary for students to engage in the design-thinking project were not present, creating a barrier for participation. Further analysis led to the conclusion that many of the young women were unable to create a new self-perception to replace the negative self-constructs they had already been created. Additionally, when asked to share their projects, many students refused from a desire to keep the information private. Despite barriers to engaging students in this process, some students were able to use the opportunity to design and promote a positive self-image and affirmation. A significant factor in the difficulty of

getting all students to engage centered on the many students who did not elect to be part of this group. Had students been given a choice to engage, the design process may have been able to engage more students in creating a positive self-image.

Middle and Elementary School

Several researchers examined the implantation of design thinking at middle and elementary school levels. The use of design thinking and user-centered approaches were purposefully integrated into the national design and technology curriculum in England. Nicholl et al. (2012) completed a study to specifically evaluate this design curriculum and determine to what degree a user-centered approach to design was being implemented in a middle school classroom with fidelity. The researchers completed the mixed-methods study in two distinctly different regions of England with a total of 50 students. Each student participated in a pre- and posttest questionnaire and small focus-group interviews. The researchers conducted semistructured interviews with administrators and teachers associated with the instruction of these students.

Nicholl et al. (2012) discovered that although teachers attempted to incorporate user-centered approaches, the end-user experience related to the design process and instruction was not authentic and lacked the intended purpose. Students were given little instruction on how to properly engage, understand the point of view, and design for an end user. As a result, many students tended to use their own age group as their point of reference during the design process. Students noted and confirmed that they did not use strategies to empathize or understand the needs of the end. Student surveys further supported these findings with 82% identifying the absence of self-observation strategies, 68% identifying the absence of user observation, and 92% identifying the failure to

incorporate simulation. All the aforementioned strategies would have provided valuable information about the end user when working with the assigned design tasks. Simply making a project more desirable for another user or themselves was not the intention of the user-centered approach to instruction. To make the learning experience authentic, a genuine interaction must occur with the user to understand and determine their needs. This social interaction leads to a social construction of knowledge essential to design thinking (Nicholl et al., 2012).

Another study on design thinking in the middle school setting examined the creation of an after-school program by university professors and graduate students. The study was conducted in an urban community in San Francisco with middle school college-preparatory students identified as socioeconomically disadvantaged and of diverse ethnicity (Carroll, 2014). The ethnographic study focused on the experience of the graduate students through the analysis of retrospective journals. Middle school students in the 7-week program received an opportunity to engage in hands-on, design-based learning activities rooted in science, technology, engineering, and mathematics education. Study results focused on the mentoring relationship between graduate and middle school students. Results surrounding design thinking demonstrated the after-school program provided a suitable environment for the development of a prototyping mindset among students. The instructors and students reported being comfortable with the failure of their prototypes, learned from those experiences, and applied those learnings to future tests. The middle school students also demonstrated ownership and agency in their learning. Additionally, they exhibited the willingness and ability to develop multiple solutions for their design challenges. However, this study was limited

by the absence of interviews or any direct feedback from the middle school students, which would have provided students' insights and perspectives on the use of design thinking.

Carroll et al. (2010) completed a similar ethnographic study with university instructors and graduate students creating instruction for a middle school geography class. The purpose of the 3-week-long study was to determine the impact of design thinking in the K–12 geography classroom. Data accrued through audio recording of the class sessions, student interviews, student artifacts, and teacher postinterviews. Middle school students received lessons on geographic systems through direct instruction and design-thinking challenges. The instructor implemented stages of ideation, brainstorming, prototyping, testing, and reflection during individual sessions during the 3-week program.

Three main themes developed from the results of the study. First, the middle school students saw design as a way to explore (Carroll et al., 2010). Specifically, they began to explore how they could be a designer, the idea of being an active change agent, and how to develop empathy for others in relation to human needs. Second, students appreciated the ability to connect with peers in an academic setting. Students acknowledged the use of hands-on activities as a way to promote the social and communicative aspects of design thinking. The middle school students exhibited collaborative aspects by voicing their ideas, concerns, and disagreements amid the process of designing. Third, students had a difficult time connecting the activities and their purpose to the actual academic content goals and standards of the lessons Carroll et al., 2010).

This study provides insights into the potential for using design thinking in the classroom, but the format and researcher participants of the study did not represent the average middle school classroom. The use of an after-school program is a very different setting from a traditional middle school classroom. Additionally, the experiences and expertise of a middle school teacher are often quite different from university-level educators. Further, many middle schools no longer have geography as a separate course.

Kwek (2011) conducted a qualitative case study on the use of design thinking in a middle school classroom. Kwek conducted classroom observations during mathematics, language arts, social studies, and design instruction classes. Additionally, the researcher engaged three purposefully selected teachers and four participating students in semistructured interviews about their lessons. The study focused on the key reasons for teachers' use of design thinking, factors that may influence this decision, and how lessons integrate content and lesson structure. A strong connection emerged between the use of design thinking in the classroom and a teacher's positive attitude toward the strategy (Kwek, 2011). A shared building-wide initiative, vision, and outward support by the building administration produced a positive attitude toward the use of design thinking in the classroom. Students who experienced the design thinking in this study were highly motivated, due to a higher sense of success and having multiple moments of sudden insight. These moments created connections to real-world experiences and required students to cognitively struggle with various concepts, leading to a deeper understanding of the subject matter (Kwek, 2011).

At the same time, the teachers noted that design thinking is not a useful strategy for every lesson or content area. They needed to adjust the use of design thinking such as

using only one aspect or stage in a lesson to properly and effectively engage the subject matter. This implementation of only specific stages or aspects during their lessons were effective in promoting student engagement and learning. Additionally, teachers did note the significant amount of time and effort needed to infuse this approach into their pedagogical approach, which may be a barrier to implementation. The teachers also recognized the time needed for implementation directly conflicted with the need to cover required and mandated content. Although this study provided many important insights into the use of design thinking, this school had the extraordinary circumstance of a focus on the use of design thinking and teachers who are highly skilled and motivated to implement this pedagogical approach (Kwek, 2011).

Although multiple researchers examined the use of design thinking and the instructional implications, Nelson (2009) conducted a study focused on the long-term academic progress of middle school students who participated in a sixth-grade design-based classroom. Nelson examined the Stanford Achievement Test scores of these students from 2006 to 2009 to determine any significant differences in performance, based on participation in design-based classrooms. Results demonstrated students made only modest gains in the first 2 years. However, during the last 2 years, students who participated in the design-based classroom showed significant gains compared to peers situated in a traditional classroom setting. Despite these positive results, Nelson noted that students in the design classroom would have most likely done well in any setting due to their academic ability and high academic motivation.

Researchers also have studied design thinking in the elementary school setting. Kangas, Seitamaa-Hakkarainen, and Hakkarainen (2013) examined 32 elementary

students, aged 10 to 11, engaged in a pendant-lamp design project. The purpose of the research was to observe the collaborative process to better understand its presence in a design-thinking activity. During the study, the researchers focused attention on the interactions of a small group of students as they engaged in the design-thinking challenge. The study found the collaboration process was evident during the study through the use of sketching, drawing, and visual representations of the design problem. The researchers noted during these activities the focus of the discussion was on the visual, technical, design constraints, and visual representation of the design object. As the group created more sketches and drawings, the discussion surrounding these design areas increased. The researchers also noticed a significant amount of off-topic talk during the sketching phase of the project. As the small group shifted to modeling and prototyping their design model, the researchers noted that new conversations and ideas were not present during the sketching phase (Kangas et al., 2013). Each participant seemed to perform a specific role in the group, which assisted them in building on ideas and the actual prototyping of a model. Most importantly, the study demonstrated how social interaction during learning activities can serve as a tool for collaborative thinking (Kangas et al., 2013).

Although this study demonstrated the positive aspect of collaborative thinking, the study focused on one small group of students. Further, the study centered on the collaborative nature of design solely without observing any other factors or aspects of design thinking. The lack of scholarship focused on the use of design thinking in K–12 and more specifically young learners is evident (Davis & Littlejohn, 2017). The use of design thinking has the distinct possibility of increasing a young learner's creative

abilities, increasing empathy for others, and developing problem-solving skills, all leading to having an impact on the lives of those around them. These possible and important characteristics demand increased research on the use of design thinking in K–12 schools.

Design-Thinking Research Implications and Findings

Despite limited scholarship on the use of design thinking in K–12 settings, some important findings and implications are prevalent throughout the extant scholarship. Design thinking necessitates a human-centered process that seeks to promote viable solutions for an end user. Researchers demonstrated that empathy in this aspect of the process is critical to the establishment of a human-centered solution (Carroll, 2014). The requirement and ability to take the perspective of another to create a solution that benefits another human being is essential in the design-thinking process (Mentzer et al., 2015). As students empathize with the end user, a momentum and understanding develop that comes from the knowledge that they are affecting and possibly improving the life experience of the end user. Students begin to see themselves as active change agents and begin to demonstrate a bias toward action, which is essential in the design-thinking process (Carroll, 2014; Kramsky, 2017).

As students move through this process, another key outcome present in the research is students' ability to learn through failure. Design thinking creates an iterative learning environment where risk-taking and failure are inherent in the process (Benson & Dresdow, 2015). The learning that occurs from failure is essential for skill development and profitable in the creation of well-designed solutions (Carroll, 2014). Problem-solving skills noted in the scholarship are an important outcome. Throughout the design-thinking

process, students were observed to acquire problem-solving skills (Apedoe et al., 2008). These skills allow students to innovate, engage, and address complex problems (Benson & Dresdow, 2015). These important problem-solving skills can serve as important tools as students engage in their future education, civic, and work experiences.

As students engage in the unpredictable nature of addressing open and wicked problems, the use of design thinking also allows students to engage with materials and processes with which they are unfamiliar (Brophy et al., 2008) The multifaceted real-world problems provide an essential condition that provokes a multimodal way of thinking, essential to the effective use of design thinking (Kangas et al, 2013; Nicholl et al., 2013). Design thinking changes the manner in which students engage in learning (Carroll, 2014). Students often must engage in hands-on learning, which enhances the understanding, engagement, and long-term retention of the content (Dowling, 2012).

Multiple researchers demonstrated that collaboration is vital among students in the design-thinking process. Several researchers specifically noted the presence and positive influence of collaboration during the observation of students in a design-thinking classroom (Carroll, 2014; Carroll et al., 2010; Lugmayr et al., 2014). Collaboration has an essential presence in design thinking and a requirement that students to listen to each other (Kangas et al., 2013). Collaboration is a foundational component to the transformation of 21st-century education (Carroll, 2014). Researchers also noted brainstorming as key a element of design thinking. Students had difficulty engaging in effective brainstorming even after being provided with specific training (Coakley et al., 2014). Further, students struggled with the ability to think freely and become innovative

in their solutions. Students tended to focus on a single solution and struggled to produce multiple solutions to the problem (Mentzer et al., 2015).

An important outcome and discussion in the literature relevant to this study surrounds the use of design thinking with younger K–12 students. Scholars contend educators should develop curriculum that engages students in problem-solving skill building for novices (Mentzer et al., 2015). Although untrained student designers are able to effectively engage in the design process (Lim et al., 2013), scholarship appears to support the implementation of a design curriculum at the high school level. A growing demand for scholarship asks educators to develop ways for younger students to examine the ability and viability of design-thinking instruction in middle and elementary schools (Mentzer et al., 2015).

The ability and opportunity to develop skills in design thinking in middle and elementary students requires further study and provides an opportunity-rich field of study. Research conducted with younger learners should focus on the understanding of appropriate curriculum to engage these novice designers. Additionally, researchers need to examine the pedagogical practices of teachers, lesson design, appropriate age progressions for content, and physical aspects of classrooms using design thinking. Researchers should also focus on the experiences of students to understand their point of view and understand how best to engage them in this innovative pedagogical approach. Future research should include which content area are most compatible with design-thinking instruction, best practices for implementation, and an examination of possible limitations (Carroll, 2014).

Design Thinking and Educator Experiences

The scholarship on design thinking in an academic setting provides a wide range of data and findings. One overarching theme identified in the scholarship is attention to teacher perceptions, their roles, and their experiences in the use of design thinking in the classroom. Retna (2016) completed a qualitative case study on the experiences of teachers in the adoption and use of design thinking. Teachers who participated in design thinking had some prior formal knowledge and training pertaining to the pedagogical concept. Teachers reported having received expert training from outside sources that ensured and developed a basic understanding of design thinking. Researchers supported the importance of a solid and foundational instructor knowledge base in design thinking, prior to use with students (Benson & Dresdow, 2015). The establishment of a foundational skill level further allows educators to properly model and demonstrate the skills necessary to engage in the design-thinking process during instruction. This ability to model is a key component to success by educators in the design-thinking classroom.

While providing instruction using design thinking, teachers searched for the right balance between educator intervention and student freedom to encourage creativity. Instructors identified that supporting and guiding students during the lesson was vitally important to the success of design thinking (Lim et al., 2013). As instructors provided support to students through feedback and interaction, they stimulation of ideas and reflection on their work increased. The shift from a knowledge gatekeeper to facilitator was an important conduit to student success (Lim et al., 2013). Teachers need to be acutely aware of how to appropriately influence student creativity in the design-thinking classroom (Coakley et al., 2014). Finding a proper balance between control and freedom

allowed for optimal conditions for students to learn, fail, and explore alternative solutions. Conversely, an unbalanced approach to teacher intervention, can leave students to develop unrealistic solutions or create a restrictive environment that hinders innovative solutions. Finding the correct balance is essential for fashioning an imaginative learning environment, enhanced by communicative teacher and student relationship (Retna, 2016).

Researchers also examined teachers' desires to integrate core-content instruction into the use of a design-thinking process. The research and experiences of educators have produced varied results. Retna (2016) reported teachers' concerns about their ability to infuse core academic content into design-thinking instruction. Teachers reported that most students were used to having a systematic approach to learning that leads to finding correct answers. The divergent and multifaceted solution and learning approach experienced through the implementation of design thinking is a possible barrier to student engagement and learning. Further, teachers reported concerns connected to the ability of students to successfully engage in real-world problem solving and questioning while engaging with core academic content (Retna, 2016). Carroll (2014) found that teachers stated that design-thinking instruction should be taught in isolation from content. Teachers found the integration of core content to be difficult and produced less than desirable results with students (Carroll, 2014). In contrast, in a study by Apedoe et al. (2008), teachers reported success and benefit from incorporating specific science content into a design-thinking project. Students not only increased in core content knowledge during the project, but in future lessons as well. Teachers reported being able to cover more core content at an accelerated rate during the school year due to the strong science-content knowledge base acquired during the design- thinking project (Apedoe et al.,

2008). Further, the ability to modify and adapt core academic content in a design thinking project was posited as a strategy for success among some teachers (Kwek, 2011). Educators suggested that a design-thinking approach is not appropriate for all content and classrooms. Rather, the instructor must carefully choose which content areas and lessons in which to integrate a design-thinking approach to benefit student learning.

As with any new pedagogical approach, the time needed to plan, understand, and prepare to deliver an effective lesson was another element present in the research surrounding teacher experiences. Teachers stressed the importance of needing time to invest in reformulating their pedagogical approach when using design thinking (Kwek, 2011). Additionally, teachers found the time available to complete projects, plan lessons, and deliver content was not realistic (Retna, 2016). Teachers cited that the increased and ever-present pressure of standardized testing creates a barrier to effective use of design thinking. Beyond the time needed to plan, teachers also noted the time and ability to set up a classroom space that is innovative, friendly, and well furnished with materials to ideate, prototype, and test are essential (Lugmayr et al., 2014). Another possible barrier beyond time and classroom space is the attitude of students toward design thinking. Norris (2014) reported that students found the process of design thinking very difficult to understand. Students did not engage fully in the process and demonstrated a lack of interest as the project progressed. The teacher noted that a lack of interest significantly affected the impact of the use of design thinking on learning.

Summary

Related literature offers various models and definitions of design thinking. Partly, this variation is due to the relatively new nature of this potential innovative pedagogical

practice. Theorists in design sought to provide a solid foundation for the use of design principles in education. Further, several models were developed that assist those seeking to implement design thinking in business and academic settings. The Stanford d.School model has gained respect among educators and is often implemented in K–12 settings. Scholarship on the use of design thinking in schools is limited, but provides a cursory review of the implementation practices and possible benefits of its use. From universities to the K–12 setting, studies showed that the benefits of collaboration, communication, critical thinking, and creativity result from design thinking . Additionally, some research suggested best practices and revealed teachers' related experiences and instructional decision making. Despite some scholarship on the use of design thinking in K–12 schools, the opportunity for more comprehensive and specific research is needed. Specifically, what does design thinking look like in the K–12 classroom? How might design thinking be integrated into the core curriculum? What are the pedagogical practices of teachers using design thinking? What barriers do teachers experience to implementation? How can design thinking assist or benefit students in developing 21st-century skills. The present study addresses several of these questions.

Chapter 3

Methods

The purpose of this chapter is to outline the methodology for this qualitative case study. This study was conducted in a seventh-grade technology education classroom to further understand the use of design thinking as a teaching strategy. In this chapter, I will detail the methodology and worldview that guided this study, the conceptual framework of design thinking, the case-study site and participants, data collection, data analysis, data reporting, researcher as instrument, criteria for trustworthiness, and limitations of the study.

Methodology

Qualitative research focuses broadly on the investigation of a social or human problem by understanding the meaning and experience of individuals or groups (Creswell, 2007, 2014). Such research is an inductive process where themes emerge from the collection and analysis of data by the researcher (Creswell, 2007). Qualitative research often involves researchers immersing themselves in a setting to collect first-hand data while observing participants. Immersion allows the researcher to access and deeply examine participants' perspectives. The researcher develops themes and concepts during the study that derive from the systematic analysis of data provided by participants. A more profound and comprehensive understanding emerges as a result of the social or human phenomenon. The researcher immersing themselves in the study invites the study and the data to inform and drive the narrative and results of the scholarship.

Several philosophical assumptions lay a comprehensive framework for understanding the goals and methods of qualitative research (Creswell, 2007). The

ontological assumption is that qualitative research recognizes, observes, and reports on the multiple realities, viewpoints, and perspectives of study participants (Creswell, 2007). The researcher provides evidence of these varying perspectives through the use of quotations and narrative that illuminate themes and the realities presented in the study. Qualitative researchers place themselves as close to the setting and participants being studied as ethically possible (Creswell, 2007). The close engagement in the study is to gain as much first-hand knowledge of the participants and setting as feasible to develop a full and comprehensive understanding of the phenomenon under study. As qualitative researchers being to place themselves into the environment of the study, they must understand and acknowledge the bias and self-perspective they interject into the study. Researchers must acknowledge and discuss this bias as they position themselves in the study (Creswell, 2007). The rhetorical, philosophical assumption of qualitative research emphasizes the use of the narrative form and personal pronouns used by the researcher in the study (Creswell, 2007). Hallmarks of qualitative studies are the use of narrative while reporting the findings of the study along with the use of pronouns to describe the actions of the researcher during the study.

The characteristics and assumptions of a qualitative research approach align well with the goals of this scholarship. The purpose of this research study was to understand the perspectives and experiences of a seventh-grade teacher and students using design thinking in the confines of a seventh-grade technology-education classroom. Further, in the study, I sought to understand the process of instruction using design thinking and how this was possibly used to engage students in meaningful learning. As the investigator, I immersed myself in the classroom environment while observing and interviewing the

participants to gain insights, collect multiple forms of data, and gain a more comprehensive first-hand knowledge of their perspectives. From this collection of data, a systematic analysis of the data occurred, which drove theme development. I used quotations and examples of participant interviews and classroom observations to expand the findings of this study. Overall, the goal of the study was to develop a better understanding of design thinking in the classroom and how this understanding may inform the instructional practices of teachers. This overreaching goal aligns directly with the purpose of a qualitative researcher to better understand a social experience through the inductive collection of data to inform common themes.

As a qualitative inquiry, this study draws on a particular philosophical worldview. A worldview is the fundamental philosophical viewpoint and orientation from which a researcher builds a study. This study employed a social-constructivist worldview. Research based on a social-constructivist point of view investigates and values the viewpoints of individuals and the impact of the environment on these viewpoints (Creswell, 2007, 2014). The researcher seeks to discover the varied and multiple meanings presented by participants, relying mostly on participants' views and experiences of the situation (Creswell, 2007). The researcher works to ask broad and open-ended questions to allow the participants in the study to freely express their experiences, perspectives, and interpretation of their interactions with others and the environment. The focus on the social formation of participants' experiences is of utmost importance and interest in this worldview. Researchers employing this philosophical construct understand and should account for their own bias, interpretation of events, and personal experiences, which may influence the scholarship. Unlike a postpositive

worldview, which starts with a predetermined theory, the primary objective of social-constructivist researchers is to induce and generate theory or meaning through the collection and analysis of the experiences of participants (Creswell, 2007, 2014). These theories or subjective meanings often emerge through the observation of the social interaction of participants with others and their environment (Creswell, 2007). To fully explore the social experiences, beliefs, and understandings of the participants in this study, a methodology guided by a constructivist worldview is appropriate.

This study employed a single-case-study approach. A case study is an "empirical inquiry that investigates a contemporary phenomenon in depth and within the real world-context, especially when the boundaries between phenomenon and context may not be clearly evident" (Yin, 2014, p. 16). Case-study research, in contrast to other research methodologies, focuses on a bounded system or case and intently investigates the real-life context and interactions of participants, and seeks to understand deeply the viewpoints and experiences of all involved. The investigation takes place over time and systematically collects detailed data using multiple sources of information such as observations, interviews, documents, and artifacts (Creswell, 2007).

Researchers collect data by placing themselves in close proximity to the study case (Creswell, 2014). The use of multiple data sources, triangulation of data, and a strong theoretical foundation that informs the collection and analysis of data are all hallmarks of this research approach (Yin, 2014). Accordingly, case studies produce well-developed and detailed themes and understandings of a specific phenomenon and are well suited to investigate complex social phenomenon (Creswell, 2007; Yin, 2014). Although a detailed understanding of the specific case is accomplished, the complex meanings

developed are specific to the case and not intended for generalizing beyond those specific boundaries (Creswell, 2007).

A case-study approach to research was an appropriate methodology for the investigation of design thinking in a seventh-grade technology-education classroom. I attempted, through this study, to better understand the possibilities inherent in design thinking and how Mr. Thomas implemented design thinking in the classroom. Additionally, this study sought to understand the unique and specific experiences of the teacher and students in a particular context and social-learning environment of a design-thinking unit in a seventh-grade technology-education classroom. The social and educational interactions of the teacher, students, and content in this bounded environment were the focus of theme development and the evaluation of the complex phenomenon of design thinking in the classroom setting. I collected data through semistructured interviews with the teacher and students, classroom observations, field notes, and artifact analysis. I reviewed the data thoroughly several times for theme development and to gain a deeper understanding of design thinking in a classroom. The goals and intended outcomes of the study aligned closely with the philosophical assumptions of a qualitative case-study approach guided by a social-constructivist worldview. The methodological approach that influenced this study was informed by the conceptual framework detailed in the next section.

Conceptual Framework

Design thinking is often conceptualized as a learning and investigative process that uses active problem solving that is human-centered, action-oriented, and focused on the ability of participants to positively implement change (Carroll, 2014; Hasso Plattner

Institute of Design, 2017). The use of design thinking as an innovative approach to learning focuses on students engaging in hands-on projects, allowing students to experience and gain empathy for others, create specific space for ideation and collaboration, and engage in active problem solving (Carroll et al., 2010). Design thinking allows students to effectively engage with complex problems that are human-centered and demand an action-oriented approach to address.

Although educators can implement the design-thinking process, as outlined by the Stanford d.School, in a nonlinear fashion, most often a linear implementation takes place early in the process. In this study, I observed design thinking, which guided the data collected through observations and interviews with Mr. Thomas and the student participants. Design thinking served as a framework for the collection and evaluation of data throughout the study. The five stages of design thinking each offered a unique opportunity to observe and evaluate study participants. Further, design thinking provided a framework for the evaluation of instructional methods, interaction and delivery of content, and possible benefits to the educational classroom environment. Design thinking, as noted above, also provided an opportunity to evaluate the future-ready skill development of students in the study.

Site and Participants

I conducted this study in a private residential school in a large mid-Atlantic state. The primary and unique mission of the school is to serve students from families with low socioeconomic backgrounds who reside in extreme trauma-inducing environments. Students who attend the school are required to participate in an enrollment process and must meet established criteria to qualify for admittance. Criteria include financial

qualifications, academic ability, and behavioral expectations. The school has three age-specific sectors that serve elementary, middle, and high school students. The students are required to reside at the school during the school year and live in gender-specific homes with professional childcare workers and several other similar-aged students. Demographically, students who attend the school are primarily from the east coast and are diverse in their ethnicity, with approximately 50% of the students identified as members of minorities.

Most students enter the school having experienced acute traumatic events that negatively present themselves academically, socially, and emotionally. The school provides students with the necessary supports to begin to address and overcome many of these concerns. Students receive college-preparatory instruction along with various opportunities to develop career and technical skills. Students also gain the opportunity to engage in social/emotional instruction and receive various psychological services. The overall vision and purpose of the school are to provide a safe and nurturing environment for students to receive a solid education, based on academic and social/emotional standards. As a result, the hope is that each student will then, in turn, be able to live a meaningful and productive life that serves others as well as themselves.

As part of the overall strategic vision, the school has sought to infuse instructional practices into the learning environment to promote critical thinking, problem-based learning, and global/cultural competence. Consequently, the school provides specific and ongoing professional development to teachers and staff around design thinking and how to infuse this innovative pedagogical approach into instruction. An overview of design thinking and the introduction of the Stanford design-thinking model was integrated at the

start of the professional-development plan. After providing the foundation for design thinking, staff professional development focused on a careful analysis of each of the five steps of the Stanford design-thinking model. The purpose was explained as well as various student activities to engage students in each individual stage. Teachers were provided support and training on how to create and revise a design-thinking project for use in their content area. Most recently, teachers received training on how to introduce specific design-thinking skills into their everyday lessons. This focus has been present for the past 4 years and continues to be a significant focus for classroom instruction.

I enacted a single-case-study approach for this study that focused on the bounded environment of a seventh-grade technology-education class. The single-case-study approach allows for a critical or specific case to be thoroughly examined, allowing theoretical assumptions to be supported or challenged (Yin, 2014). The classroom in this study was part of a set of exploratory classes that allowed middle school students to explore various subjects such as art, physical education, health, careers, dance, music, art, and technology. This classroom was purposefully chosen for this study because it allowed students to explore engineering and technology while using power equipment and advanced technology to create hands-on projects. The instruction in the classroom was well suited to and often used the design-thinking process to allow students to engage in classroom instruction and participate in projects.

The study participants consisted of a seventh-grade technology-education teacher and the seventh-grade students assigned to the teacher's first-period technology education classroom. For this study, I used the pseudonym of Mr. Thomas for the teacher. Mr. Thomas was purposively selected to participate in this study. Researchers use purposeful

sampling when participants possess a unique ability to inform and provide specific and meaningful insights into a specific situation or phenomenon (Creswell, 2007). Mr. Thomas has more than 15 years of experience instructing high school and middle school technology-education classes in various school districts. He has been teaching in his current setting for the past 6 years. The majority of his experiences include engineering, manufacturing technology, robotics, and hands-on student projects. Over the past 4 years, Mr. Thomas has engaged in year-long professional development courses on design thinking. He has also demonstrated proficiency in implementing design-thinking strategies and instruction in the classroom. The unit chosen for this study included students participating in a design-thinking project creating aerodynamic wooden CO_2 race cars over approximately 6 weeks. The study entailed observing the process of the creation of these race cars from start to finish and the use of design thinking as a tool for instruction.

The classroom consisted of seventh-grade students who were chosen as participants because they are assigned to Mr. Thomas during the specific time period of this study. The students were of varying genders, academic abilities, and ethnicities, and came from low socioeconomic backgrounds. Students ages ranged from 12 to 13 years. Although this design-thinking project was original and unique to the students, some students had previously engaged in design-thinking projects or similar instructional strategies in other classes. Beyond the students who all participated in the classroom observations, I asked several students to participate in individual interviews. I chose four students, two boys and two girls, randomly from the classroom list to participate in the interviews. One girl identified as Caucasian whereas the other identified as Hispanic;

both male students identified as Caucasian. I assigned the students the pseudonyms of Emma, Miracle, Mark, and Steven. Students in this study were able to provide specific insights and perspectives from their experiences with design thinking, the project on race-car development, and the classroom environment. I invited Mr. Thomas and the students to voluntarily participate in the study. Mr. Thomas and the parents of the students assigned to the class were asked to review and sign a consent form prior to participation in the study (see consent forms in Appendix A and B). I asked students to sign assent forms to participate in the study (see assent form in Appendix C). All participants were able to withdraw from the study at any time.

Data Collection

This qualitative case study employed semistructured interviews, classroom observations, field notes, and collection of documents, and physical artifacts as data sources. The use of multiple sources of evidence increases the ability of a researcher to better understand the phenomenon being studied (Yin, 2014). Although each of these data-collection methods is inherently biased in some manner, the use of multiple sources reduces and limits the influence of these biases.

Observations were a chief data source of data for this research study. I observed seven of the nine classroom sessions in the identified seventh-grade classroom. Additionally, I observed a final optional class session in which students in the class could race their final cars. Each of these class periods was digitally audio recorded. Direct observations allow for first-hand experiences with the bounded case and recording of real-time information as it occurs (Creswell, 2014). Throughout all observations, I collected detailed field notes. As the researcher, I was not part of the classroom

instruction but sat in the classroom to observe the environment and student and teacher actions. On occasion, I walked around the room to observe students working on various aspects of instruction. I was mindful of my possible interactions with students to ensure or reduce the possible influence I might impose. I also took field notes during the observations to serve as supplemental support to the audio recordings of the classroom lessons. Additionally, after each class observation, I transcribed the audio recordings, supplemental notes, and observations within 24 hours of the class period. Direct observations are limited in that researchers can be seen as intrusive, influence the behavior of participants, and inadvertently omit important information (Creswell, 2014). Due to the extensive time spent in the classroom, the influence of my presence was vastly reduced.

I also collected physical artifacts and documents as evidence for this study. Documents are especially useful in case-study research to validate and strengthen the findings drawn from other collected sources (Yin, 2014). Additionally, the collection of physical artifacts and documents provided technical and specific information that may have been influential and important in understanding the context of the case study. Physical artifacts collected during this study included handouts, design-thinking packets, and pictures of classroom instructional information and student work. I reviewed the artifacts for relevance and included them in the overall coding process as I determined themes.

I conducted semistructured interviews using a predetermined script of open-ended questions (see teacher and student question protocols in Appendix D and E). I interviewed the seventh-grade technology-education teacher at the beginning and end of

the study. The interviews lasted for no more than 1 hour and were digitally audio recorded. I had the audio interviews transcribed for analysis using a transcription service. Additionally, I sought clarification from the teacher about several themes and items seeking clarification through verbal conversations and e-mail. I interviewed the four students at the middle and end of the study. These interviews lasted no more than 30 minutes and were digitally audio recorded. A transcription service transcribed the audio interviews after each session. Semistructured interviews allow for flexibility and adaptation of questioning during the process (Thraen & Jan, 2016; Yin, 2014). The structure of this type of interview also allows for more free and open discussion, permitting the researcher to adjust, as needed, to further investigate important themes (Eisenhardt, 1989). Interviews enable a researcher to gain insights and the personal perspectives of the participants (Yin, 2014). Limitations of interviewing as a data-collection method include question bias, recall errors, and participants answering to please the investigator (Yin, 2014). I attempted to mitigate these potential limitations by balancing interview data with other forms of data collection in this study.

Data Analysis

I coded the data to develop major themes and areas of significant learning from the research. I used inductive and deductive data analysis. As already noted, data included in the analysis were teacher and student interviews, classroom observations and field notes, and artifacts collected during observations. Researchers use inductive data analysis to create themes and broad patterns to develop a more specific theory or understanding of a phenomenon (Creswell, 2014). To analyze the data, I employed an inductive approach, employing Tesch's coding procedures (Creswell, 2014). Tesch's

coding procedure builds on eight specific steps that result in the production of common themes from the data collected. First, I read and carefully reviewed all transcripts of interviews, field notes, and artifacts. I took notes on possible themes or commonalities during this process. Second, I chose a primary document, notes from a classroom observation, and reviewed it more closely while seeking underlying themes and asking myself what the document was mostly about. I took notes in the margin of the document. Third, I completed this process for multiple main pieces of data. I created a list of possible topics and themes I defined, collected, and created. I then created an initial theme organizational framework. Fourth, I evaluated all the data through the framework using abbreviated codes representing the initial themes. I looked to see if other themes emerged or if the initial themes were further supported. Fifth, I used a descriptive wording for the initial themes and translated them into categories. I attempted to reduce the number of categories by identifying possible connections or commonalities between themes. Seventh, I organized and further analyzed the data specifically by category. Last, I looked for the possible recoding of any data (Creswell, 2014).

To thoroughly examine and understand the use of design thinking in a K–12 academic setting, I also engaged in deductive analysis of the data. Researchers using deductive analysis use a theory or framework and search for evidence to establish or repudiate its presence in the study (Creswell, 2014). Design thinking provides several distinct stages of implementation and provides several themes or categories from which to examine the data. During this process, I took each step of the Stanford d.School design-thinking model independently and used them to examine the data for examples. In

other words, I reviewed the data to determine the degree to which the stage or element was present or absent in the case.

Data Reporting

To effectively communicate the findings of this study, I used an organized system for the collection, organization, and reporting of the results. I organized the data through specific coding and analysis methods, which produced common themes. The development and reporting of these common themes were supported and deeply rooted in participants' own words, which were shared generously.

Researcher as Instrument

As an educator of 21 years, I have been interested in the potential impact of innovative teaching strategies that disrupt the traditional teaching environment and provide students a skill set they can use to engage in complex problem solving. As a building administrator for 12 years, I had the opportunity to redesign a traditional computer-skills classroom. The classroom offered traditional instruction in word processing, presentation software, and typing. To begin to explore the redesign of this specific curriculum, I attended national conferences, researched peer-reviewed educational journals, and searched the Internet for current trends in technology education in schools. As part of this research, I learned about design thinking in education. After some additional research and discussion with fellow educators, I became extremely interested in the possibilities that design thinking could provide students in a classroom setting. In cooperation with a teacher with similar interests, I was able to create and implement a new technology curriculum based on the principles of design thinking. During this implementation, I began to understand the impact of design thinking and the

potential benefits to students. Having observed this pedagogical approach in practice for several years, my interest in design thinking has increased with a specific focus on the best practices for implementation in the classroom setting.

Since the implementation of this new curriculum, design thinking has become one of the central foci of my school district. As part of the strategic vision for educational practice, the district has identified the use of design-thinking-infused instructional practices as one of the main classroom emphases for the past 5 years. Due to my interest and knowledge of design thinking, I have led and continue to lead monthly professional-development sessions for teachers, specifically focused on understanding and implementation of design thinking in the classroom. These professional-development sessions assist teachers in understanding the overall philosophy of design thinking, stages of design thinking, how to implement them in the classroom explicitly, and how to develop instructional projects based on design thinking. Most recently, the focus of these professional-development groups has shifted to the implementation of design-thinking instructional strategies into everyday classroom lessons throughout the school year. Due to these experiences, I have also had the opportunity to present at several educational conferences on the use of design thinking.

I have personally seen the potential of design thinking in the classroom to increase the collaboration, critical-thinking, and future-ready skills of students. Because this is a somewhat new approach in K–12 schools, limited research or practical literature exists on the topic. Despite some practical texts recently available to educators, the dearth of empirical evidence continues. My belief in design thinking as a disruptive and innovative teaching strategy, along with the lack of empirical evidence, has driven me to

pursue this study. Specifically, I am excited to engage in research on design thinking in my district.

I have personally invested much time and effort into supporting the initiative to implement design thinking in the district. Additionally, I have worked directly with the teacher in this study to understand design thinking and implement projects in the classroom. As a result of conducting this study, I have developed a deeper understanding of how design thinking is implemented in a classroom setting. Further, I have gained new insight and understanding of the experiences of teachers and students as they interact with design-thinking practices in the classroom. Although I brought strong assumptions about design thinking to this project, I remained open to learning new aspects of the affordances and constraints of this instructional approach. I am hopeful this investigation will add to the current empirical research, providing a further example of the potential benefits and challenges of using design thinking as an instructional method.

My passion and belief in design thinking, my leadership and investment in design-thinking implementation in the district, and my professional relationship with the teacher in this study had the potential to influence this study. First, I acknowledge my bias toward the potential of design thinking as an innovative teaching strategy. My predisposition to the positive aspects and a predisposed enthusiasm toward design thinking had the potential to influence the lens through which I observed the content and evaluated this study. Second, the desire to see the positive impact and implementation of the professional development I helped provide created a risk of bias. The third area of potential bias is my desire to see my colleague and the students in his class successfully engage in design thinking. Despite these acknowledged areas of bias, I leveraged the

potential to use my knowledge base to carefully and systematically seek evidence that supports and negates the value of design thinking. It was vital that I continually acknowledged these areas of bias and reminded myself to collect data systematically. I was critically evaluative in this case study, as needed, to provide an accurate representation of the case, along with suggestions for future practice and research.

Criteria for Trustworthiness

I took careful steps to ensure this study produced trustworthy findings. Validity in a qualitative study requires the researcher to examine findings for accuracy from the perspective of the researcher and the participants (Creswell, 2014). This study employed the triangulation of data through the collection and use of multiple data sources to strengthen the validity of the resultant findings (Yin, 2014). Triangulation of data occurs when researchers collect and analyze multiple sources of data. Triangulation of the data in this case study occurred through the collection of multiple participant interviews, observations and field notes, and artifact collection. I analyzed these sources of data multiple times in search of common themes and conclusions for this study. Triangulation of data through multiple participants and forms of data provided a wide range of data sources and information, which increased the validity of the study.

Qualitative researchers increase the credibility of their research by openly and honestly discussing the bias that influences their study (Creswell, 2014). This study directly addressed researcher bias when I appropriately and openly discussed how bias may have influenced the study. Spending a significant amount of time in the field or setting of the study also increases the validity of the study (Creswell, 2014). By spending substantial amounts of time in the field, I obtained a rich and detailed understanding of

the case. This detailed understanding led to increased credibility and the ability to engage in accurate narrative writing. As the researcher, I attended seven of nine classes and a final optional car-racing session to gain this vital perspective.

Also crucial to the validity of this study was the discussion of opposing themes. The discussion of opposing themes in case-study research ensures the reader of an authentic interpretation of the case (Creswell, 2014). As the data were analyzed and reviewed, I presented themes that opposed or demonstrated weakness in the use of design thinking to gain a complete examination of this phenomenon.

Reliability in case-study research assumes the researcher systematically operationalizes procedures and collection of data such that a future researcher could conduct the same study (Yin, 2014). I clearly outlined the procedures for the collection of data, audio-taped class observations, and participant interviews, and controlled for code-definition drift. As noted earlier in this chapter, I outlined and implemented clear guidelines for participant interviews, observations and field notes, and artifact collection. Additionally, I established and executed systematic measures for coding and data analysis. The specificity of these procedures support the reliability of this study.

The audio recording of participant interviews and observations allowed for the review of transcripts and field notes for accuracy (Creswell, 2007). The audio recordings assured the accuracy of the transcripts and allowed for the addition of any missing relevant data. As analysis of the data occurs, a shift in the meaning of established codes can occur that directly affect the reliability of the study (Yin, 2014). To reduce the shift-code definition, I recorded a clear definition of each code and occasionally reviewed the data assigned to each code (Creswell, 2014). Additionally, I used member checking with

Mr. Thomas to solicit feedback on my initial findings and analysis from the study. Member checking provides credibility and reliability to the findings as does soliciting feedback from participants about what information may have been overlooked (Creswell, 2007).

Case-Study Limitations

Qualitative research has often been considered to be less scholarly and rigorous as a research approach (Yin, 2014). The lack of a specific scientific method along with the consistent practice of using a small population of participants leads to this conclusion. Many question the rigor and the lack of specific methodological procedures of case-study research (Yin, 2014). However, case-study research provides a methodology that allows for an intense and specific study of a phenomenon or bounded case. As with any methodological approach, the use of the case-study methodology has some limitations. The perceived lack of consistent practice and scientific guidelines for case-study research in comparison to other established methodologies leads to some skepticism about this methodology. However, case-study research guidelines and systematic approaches are becoming more common and established in the research community (Yin, 2014). Another limitation or concern with case-study research is the amount of time and information needed to complete a study, which may cause the researcher to become overwhelmed (Yin, 2014).

The small number of participants in this single case study makes it impossible to generalize to other populations (Yin, 2014). Despite this limitation, case-study research can be highly impactful for school districts or teachers considering the use of design-thinking pedagogical practices. Bias, sensitivity, and the integrity of the researcher limit

case-study research (Merriam, 2009). The bias of the research has the potential to influence the collection and analysis of data in the study. Additionally, the researcher alone is responsible for personal perspectives and abilities to engage in case-study research. The lack of unbiased evaluation and necessary skills can lead to a study with inaccurate representations. However, case-study research provides no greater risk of researcher bias than other forms of research (Flyvbjerg, 2006). To reduce bias, I collected multiple sources of data, implemented member checking, reviewed findings with my doctoral chair, and ensured that I remained open to all possibilities of data interpretation.

Another limitation of this study was the setting in which it took place. The school where this research took place is unique compared to most schools in the United States. First, the majority of students in the United States do not attend residential schools. Second, the student population comprises low-income students with exposure to many adverse trauma incidents who are not being educated in their home community. They are placed in an upper-middle-class school and home environment in which they live and attend school. Although many of the issues associated with poverty and trauma persist in their daily lives, the setting in which they live and learn is unique to them and vastly different from their home communities. The unique setting further increases the lack of generalizable findings to come from this case study. Further, the specific classroom setting for this study was an exploratory classroom that students only attended for nine class periods. The reasons mentioned above limit the transferability of this study's findings to a core classroom setting in which students will engage in core content during the entire school year.

Summary

I conducted this study using a qualitative case-study approach to gain first-hand knowledge of the topic of study. My immersion into the case allowed for a personal and comprehensive examination of design thinking. Case studies create well-developed and detailed themes and understandings of a specific phenomenon and are well suited to investigate complex social phenomenon (Creswell, 2007; Yin, 2014). I leveraged the case-study methodology to fully immerse myself in the environment to understand the perspectives and opinions of the study participants. I employed a social-constructivist worldview that relied on the viewpoints and environmental influences of the participants. I conducted the study in a residential school that specially focuses on the education of students from low-income families. A seventh-grade technology-education classroom and the assigned students served as the participants over 5 weeks. Data accrued using participant interviews, classroom observations, and artifact review. I analyzed the data using inductive and deductive coding with major theme development used for data reporting. The use of multiple data sources and forms of data contributed to the triangulation of data. Reliability further increased through significant time spent in the classroom and through member checking. Although the results of the study were unique to the setting, practitioners may use this research to evaluate and improve their pedagogical practices.

Chapter 4

Findings

In Chapter 4, I review the findings from this case study. The findings include a comprehensive description of how one teacher employed a design-thinking approach with students creating CO_2 race cars. This description will provide detailed information of the structure of the classroom, instructional methods, and student activities. I provide a full review of the evidence or absence in the data of each stage of the Stanford d.School design-thinking model. Finally, I examine the possible benefits or limitations in teaching and learning as a result of the use of design thinking. I will substantiate all findings by providing ample evidence from observations and interviews conducted during this study.

Employing a Design-Thinking Approach

During the beginning of the rotation, Mr. Thomas provided an overview of the class procedures, safety instructions, the content, and the project. As he introduced the project, Mr. Thomas emphasized his desire to "gain ideas about what they might like to do in the future and what pathways they would like to explore further" (personal communication, January 15, 2019). Although each student had an opportunity to engage in the creation of the project, the overall goal was to expose students to technological experiences and concepts such as design thinking.

During an overview of necessary classroom procedures and rules, Mr. Thomas reviewed examples of how students may have used design thinking in previous classrooms. Specifically, he recalled the use of design thinking in a sixth-grade project in which some of the students in the class had participated. During this discussion, the instructor challenged students to "come in with a good attitude and give their best"

(personal communication, January 17, 2019). Further, Mr. Thomas emphasized "holding students to a high standard when working on equipment" to ensure student safety and excellence. Mr. Thomas shared with students a brief overview of the project. "We are going to build or come up with an idea or prototype for a car." Students took a walking tour of the power tools and equipment used during the classroom instruction and project. At each station, Mr. Thomas quickly explained how each tool or piece of equipment would be used to accomplish a particular stage of the project. Mr. Thomas concluded his introduction and expectations by expressing the importance of "talking to other students and problem solving" to "create a community."

During the start of each class session, students practiced measurement using the metric system. Mr. Thomas asked students why they would need to practice measurement for this project, and one student quickly answered, "So our cars will not be lopsided." Mr. Thomas provided further instruction on the metric system using centimeters and millimeters with the use of rulers. Students commented on how confusing this can be. To address this student need, Mr. Thomas explained the use of a timed 1-minute computerized ruler game that would help them become more confident in their measurement skills. Mr. Thomas recorded student scores in each class session to help track their progress.

Following this task, students received a worksheet packet entitled "CO_2 Design Thinking Packet." Mr. Thomas began to provide a more in-depth look at the project and what role design thinking was going to play in the classroom instruction. He asked, "What is a CO_2 car? How does it work? How do we design it? We need to talk about design thinking." He explained the purpose of the packet and how it would "guide them

through the process." To begin the process of design thinking, Mr. Thomas focused students on identifying the end goal of the project. He challenged students to think about "what is going to make your car the fastest, which is the overall goal." He further explained that students would need to think about the building process and prototyping to accomplish this goal. Mr. Thomas encouraged students to begin thinking about many aspects of the car that would need to be considered during their prototyping.

Mr. Thomas asked students to brainstorm how they were going to make their cars fast. Students appeared reluctant to answer; many did not raise their hands at first. Mr. Thomas challenged the students to think about how the car would be powered. One student stated they could "use a can of CO_2 with a cap." Mr. Thomas directed the discussion to the origins of CO_2 and its presence in the atmosphere. As the discussion continued, Mr. Thomas introduced additional scientific principals surrounding laws of science, noting "The law we are focusing on is Newton's Law of Motion: Equal but opposite reaction." He further explained the process of using CO_2 compressed gas to power the cars and asked the students about how the CO_2 cars might be controlled to race them safely. One student suggested "putting up walls." Another student suggested that the back of cars could be made larger to "keep down the car more." Mr. Thomas stated this this was a good thought but that it would not control the car. The teacher provided additional explanation about metal loops on the bottom of the cars and fishing wire, which could be used to keep the cars in place once the CO_2 compressed gas was released to power the cars. As the discussion surrounding keeping the cars under control while racing continued, another important concept emerged. A student mentioned traction and the importance of having a proper grip when racing a car. Students were able to identify

that spinning wheels would be a problem, and although zero friction would be ideal, this was not physically possible. Mr. Thomas stressed the importance of understanding how the car works to begin to discuss design criteria.

Mr. Thomas developed the discussion on design criteria for a CO_2 car using the following activity. Students received post-it notes and Mr. Thomas asked them to "write design criteria down you think will change the outcome of your car and make your car faster than the kid sitting next to you." Students began to brainstorm and write down several criteria on the post-it notes provided (see post-it note examples in Appendix F). Mr. Thomas had the students share their criteria ideas with others around them, directing, "Underline the ones that are the same and talk about the ones that are different." Students formed pairs and small groups and began to discuss the criteria they thought were most important. The conversations sparked some debate. One student stated, "Size and weight are the most important," whereas a peer noted, "Resistance is most important." After several minutes of debate, Mr. Thomas asked students to write their criteria on the front board of the classroom. Mr. Thomas encouraged students to continue to add to the board if they felt strongly about any criteria that were not present. Several students approached the board and added to the list of design criteria (see student defined criteria board in Appendix G).

After students had ample opportunity to add design criteria to the board, Mr. Thomas engaged the students in a discussion evaluating each design criteria listed. The conversation began when Mr. Thomas asked the students to review the criteria on the board to determine if there were items they did not think about when they were brainstorming. Many students raised their hands affirming they saw design criteria they

did not think about during this activity. Mr. Thomas stated, “This is why we do this. I could stand up here and tell you what matters. But this gets you thinking about what matters.” The classroom discussion that followed was a review of each of the criteria listed on the board. The students evaluated the design criteria for their effect and importance in making a fast CO_2 race car. Mr. Thomas challenged the students to think about what the car does and “if they had control over it.”

Resistance was recorded as one factor that may need to be considered when designing a car. After some initial discussion, Mr. Thomas noted, “Our track is flat. So, do we want extra resistance with extra weight pushing down on us?” A student responded, “No, you don’t want it heavier ’cause if they have the CO_2 thing it is powered by then if it is light it will go faster.” Mr. Thomas explained the need to have a light car and connected resistance to the design factor of weight. Wheels were another design factor that elicited classroom discussion. A student explained, “they matter because if you have bigger wheels they have to spin less but if you have smaller wheels it has to spin more times to get down the track.” Mr. Thomas encouraged the critical nature of this thinking but explained why this would not be a factor for their cars. A student suggested that the concept of friction from the wheels may be a factor to consider. The student stated, “They might be made of different materials and stick differently to the ground.” Mr. Thomas explained how friction would be a factor they should attempt to eliminate from their car, and the role wheels may play in creating friction. He emphasized the importance of remembering wheel choice and friction at the end of the design, claiming “I have had lots of students make really good cars but drop the ball at the end and don’t think about wheel choice.”

Aerodynamics was another design factor the students documented. A student explained aerodynamics as "the resistance of something … the air coming on the car on the front." Mr. Thomas further explained that, for this project, aerodynamics plays a role in how the car moves through the air on the race track. He strongly emphasized that how students shape their car was extremely important during the project. A student noted, "It looks like if you have a triangle shape at the top, it might slice right through the wind." The class discussed the concept of shaping their car aerodynamically with smooth surfaces and how during the process of creating their car, through sanding and painting, this would be important to remember.

As the classroom activity began to conclude, a student asked, "Would the lightest weight be good"? Mr. Thomas stated, "Size and weight of your car are going to factor number one." He went on to explain that because the cars are all powered equally by CO_2 cartridges, all these factors, and especially size and weight, is how students can make their car faster than those of their peers. Mr. Thomas advised students to remember these factors as extremely important. Students received a worksheet that outlined many of the design factors discussed during class to reference as they continued during the design process (see Forces that Effect a CO_2 Car's Performance in Appendix H). Mr. Thomas also explained that students must "mesh all of these factors and balance them out" to create a fast car. He noted there is not a perfect design or a single right solution when creating a CO_2 car.

As a next step in the process, Mr. Thomas introduced the concept of design thinking and how the process would be used during the class project. He handed a packet to each student and asked them if they recognized the design-thinking process on the

front of the packet. Most students responded by slowly raising their hands. Mr. Thomas explained, “I want you to remember this process because we are going to use it for a lot of different things.” He went on to explain how the design-thinking process is used in his content area but might also be used in their mathematics and science classes in the future. As part of this project, Mr. Thomas explained that the design-thinking process would be used “to keep you on track when you are trying to solve a problem.” He further explained the importance of having a plan to solve a problem and how the design-thinking process can provide a framework to carry out the plan. Mr. Thomas stated that the design thinking packet “breaks it down step by step and keeps it on track.” (See The Design Thinking Process Building CO_2 Dragsters packet in Appendix I.)

Mr. Thomas briefly reviewed the steps of the design-thinking process with students and how they would be operationalized during the project. He noted *identify* was the first step in the design-thinking process. Mr. Thomas referenced the previous activity of defining the goal of creating a fast CO_2 car and criteria for design as essential parts of the identification stage. He recalled, “Our goal is to make the car go the fastest.” When reviewing *empathize*, Mr. Thomas explained that if they were going to design cars for an end user or company, they needed to empathize with the need for fuel efficiency. Mr. Thomas reminded students they were designing to meet their needs, making a car that will be faster than those of their classmates, and incorporate design properties discussed earlier. Mr. Thomas explained *define*, the next stage in design thinking, as the predetermined set of specifications provided to the students. Mr. Thomas explained, “We are going to follow those rules because as a designer, you typically don’t just get an open box of material and design.” He asked students to share their understanding of the next

design thinking stage, *ideate*. A student hesitantly shared, "Come up with an idea?" Mr. Thomas affirmed her response and shared how students would be looking at various models of cars to develop an idea for a prototype of their race car. He asked students the purpose of the design-thinking stage, *prototyping*. A student responded, "Make it better," and another student responded, "Test it." The remaining class discussion included an explanation of the *test* and *evolve* stages of the design-thinking process. Mr. Thomas explained how their prototypes, and eventually actual race cars, would be tested for possible redesign.

As the overview of the design-thinking process concluded, Mr. Thomas invited students to begin to engage with the design-thinking activities provided in the packet. Mr. Thomas instructed the students to look at the first page of the packet and identify the problem they were attempting to solve for this design-thinking challenge. He encouraged students to write, in their own words, what they believed to be the goal or challenge of the project. Student responses included "Make the car go as fast as possible to beat my classmates," "Get in first place with the CO_2 car," and "I want to make the lightest and most aerodynamic car." He then instructed students to review the predetermined specifications and criteria for the car design listed on the front board and record them in their packet (see teacher defined criteria board in Appendix J). Students had extra lines for criteria they discovered during the design process that might be helpful. Mr. Thomas stated the packets are useful so as "you build your car, these are all things you will need to keep in mind. Having these criteria is beneficial."

Following the identification of the problem and specifications, students began the process of the ideation surrounding their CO_2 cars. Mr. Thomas directed the students to

the ideation pages of the packet and explained, “This next page starts the ideas flowing.” Students had eight spaces to create possible solutions for their cars. Mr. Thomas provided completed examples of CO_2 race cars and encouraged students to use Google Images to search for CO_2 dragsters. Additionally, students received visual examples of previous race cars and Mr. Thomas encouraged students to explore these to benchmark ideas from others. He further encouraged them to be discerning, using their knowledge of criteria, and to understand that “not everything out there is a good idea” (personal communication, January 21, 2019). Students quickly began to explore images of CO_2 cars using Internet search engines. Some clicked on thumbnail versions of cars to expand the view for a more detailed model.

After several minutes, Mr. Thomas encouraged students to begin to sketch an idea they might like to create on their ideate page. Students provided a side and top view sketch for each possible solution. Mr. Thomas challenged students to discriminate about some of the examples they discovered. “If you see a car like that [hot dog car], are they meeting the same challenge?” The students quickly answered “no” and continued to explore possibilities. As students explored, they engaged in conversation with each other surrounding various car ideas. Mr. Thomas encouraged students to “use their resources” and as a result, students began to move about the classroom. Students explored finished models of cars in the classroom as well as drawings of CO_2 cars posted in the room. Several students asked for assistance as to how to sketch the cars on the ideation page. Mr. Thomas provided a minilesson in the back of the classroom for the students. A student asked, “How do I draw this round”? Mr. Thomas used the model sketching posted in the back of the room to further demonstrate the drawing technique and physical models

for greater visualization. Collaboration among students continued as the sketching process progressed. Two students used a blank model from which the cars would be made, to further discuss the design. Other students spent most of their time looking at images on the computer and searching for fun or different cars.

After about 20 minutes of sketching, most students began to complete their eight drawings. Mr. Thomas encouraged the students to "begin to focus on one and switch packets with a peer and get feedback on which would be most desirable." Students exchanged packets with each other, however they provided little or no substantive feedback. Mr. Thomas instructed the students to gather around a table in the back of the classroom for a demonstration on how to sketch the design they chose as the best possible solution for their CO_2 car (see teacher sketch demonstrations in Appendix K). Mr. Thomas used graph paper and a rough sketch completed earlier to provide instruction on how to create a more detailed and exact final sketch. He showed students how to use French curves and rulers to make a more finished and accurate drawing. A student shared her pleasure with her design, stating, "I did not use a ruler for this section but just estimated." Mr. Thomas encouraged the use of tools throughout. He commented, "I see people using their tools and not just simply drawing." In one student's sketch, Mr. Thomas noticed a lack of symmetry in part of their final design. He explained, "What I need you always, always to do is connect a line from here to here and use a French Curve which will give you a solid line instead of a sketch line."

During the final-sketch process, students began to investigate and ask questions on implementing the criteria for the race car into the final sketch. Mr. Thomas reminded the students, "So folks, a couple of things in case you are stuck. These numbers are up

here for length and line of symmetry" (personal communication, January 23, 2019). A student asked, "How do I make sure it is the right length?" Mr. Thomas proceeded to explain using the metric system to figure out the correct measurement in millimeters with the student. Another student quickly realized the need to create a car slightly larger than the minimum size to allow for sanding during the final creation of a race car. Mr. Thomas explained the importance of symmetry to another student noting, "The goal is to have your car be the fastest" and "it is important and easier when you go to cut and sand the car." I observed Mr. Thomas giving individual feedback to students as they implemented their final designs. Several students sought assistance from peers during the process to ensure their drawings were accurate and incorporated the established criteria (see student sketching in Appendix L).

As several students became ready to move onto the next step, Mr. Thomas once again provided a full-class demonstration. He used a student's final sketch as an example due to the "crisp lines and not a lot of eraser marks." Mr. Thomas emphasized that mistakes are acceptable and should be expected when creating a design. However, students should sketch lightly on the final design. He further specified clean and crisp lines are helpful when cutting out their final design on the band saw. He provided the students a demonstration on how to use red wax paper to transfer their final design onto a paper pattern (see sketch transfer in Appendix M). He showed students how to cut out the paper pattern and glue the pattern onto a foam prototype block. After the demonstration, students returned to work at various stages of the project. Mr. Thomas continued to circulate the room providing support and encouragement. Students quickly completed the transfer and cutting out of their pattern and were ready for the next step in the project.

Mr. Thomas instructed everyone to gather around the foam cutting machine after they secured a pair of safety glasses (see foam cutter picture in Appendix N). He asked, "Are we going to test our prototypes?" The student answered in unison "no." Mr. Thomas explained that was correct, because they would not withstand the force of a CO_2 cartridge. However, "Getting you visually to see your design is one of the most important factors of making this prototype." Students were instructed they would be able to see and make changes to their car to improve the design. Mr. Thomas demonstrated how to glue the paper template of their final sketch to the foam block. He then demonstrated how to properly and safely cut out the foam block using the foam cutter. Then, he again released students to continue working.

As students begin to create their foam prototypes, they experienced some difficulty in cutting out their top views. The students noticed that the top template did not fit the length of the foam prototype. A student asked Mr. Thomas, "How do I make this fit"? Mr. Thomas responded, "So this is always a problem for people. So, it looks like you messed something up. You did draw it the right length. But why is it not fitting is the question." Mr. Thomas challenged the student to think and solve the problem of why the top template did not fit. After some time, Mr. Thomas cut the top template in half and the after a minute, the student stated, "It is still not right. I am so confused. I don't understand." After some additional time and instruction, the student was able to figure out the proper manner of pasting on the template, realizing the curvature in the car was preventing the template from fitting correctly.

After the creation of the foam prototype, students proceeded to the next step of the process of testing and evaluating their prototype. Mr. Thomas had the students gather

around the downdraft sanding tables and wind tunnel for the next demonstration. He emphasized the importance and purpose of developing a prototype stating, “The prototype is to teach you what you like and what you don’t like and make final improvements to your final design” (personal communication, January 25,2019). He explained how students would use a wind tunnel and scale to provide data points for drag and weight. (See wind tunnel and scale pictures in Appendix O.) He further explained how the wind tunnel creates drag on the car, posing the question, would less drag make a “faster or slower car?” Students responded “faster.” Mr. Thomas noted that they should be aware of the drag coefficient of their peers to determine if their car was well designed. “You can learn just as much from your own prototype as you can from your friends.”

Mr. Thomas directed students to use their design-thinking packets to record the data from the wind tunnel and scale. He placed a full foam block in the wind tunnel and tested it as a baseline for all students. The full foam block recorded a drag coefficient of 33. Mr. Thomas then took a student example and put it into the wind tunnel. The drag coefficient on the test prototype went from 33 to 21. Mr. Thomas asked, “Do you think that you could take this and make it more aerodynamic?” The students responded emphatically, “Yes.” Mr. Thomas challenged the students to consider “What do I need to change?” He empathized that students had nothing to lose by making changes, as this was simply a prototype. Even if they made changes they did not like or that did not produce the desired results, they were still learning. The class discussion then pivoted to what actual changes could be made to a prototype.

Mr. Thomas pointed out that a peer’s car may have a drag coefficient lower than their car. He encouraged the students to think about these data and consider that “his is

more rounded or his is smaller in the back and what you can learn from that." Mr. Thomas then solicited ideas about other changes students might make to their cars to improve them during this testing phase. A student suggested "making the back more rounded." A student suggested the foam cutter could be used to "cut some off the back," which Mr. Thomas agreed was a good idea. He also suggested that students sand the foam prototype. A student interjected, "sand the waves." Mr. Thomas supported this suggestion and noted that making the prototype smooth would be helpful.

Another student suggested one could "make the front thinner." Mr. Thomas warned that making the front too thin may cause the prototype to snap. However, students were again encouraged to learn from mistakes while making the prototype and how this would need to inform their final car. "Can you still learn a lot when you make mistakes on the prototype? Absolutely." Mr. Thomas asked students to spend an adequate amount of time during this testing and evaluation process to learn and make changes to improve their cars. Mr. Thomas stated, "What I don't what to see is I make my cut and then test and get 10 and say I am done with this, it is pretty good, and move on."

After a significant discussion on the aerodynamic testing of the prototypes, Mr. Thomas asked students to evaluate the weight factor as well. Mr. Thomas shared, "We are going to focus on how much does our car weigh. Sam just mentioned that the weight of the car is very important." He introduced the jeweler's scales to students and described their accuracy and fragile composition. (See the scale in Appendix 0.) Mr. Thomas weighed and measured an original foam block at 8.90 grams. Mr. Thomas cautioned students about being presumptive about their car's weight. He noted, "it is relative to the others around you." He further challenged students to be aware of the weight of others'

cars and to record their car weight as they made changes. Before releasing the students to begin working on their cars, he demonstrated the sanding technique for the cars. Mr. Thomas reminded students "a couple of drags of sanding can make a big difference." He then cautioned students to follow the steps described. "If you do not have a good baseline to compare against then you are just guessing if your prototype is good or not." He released students who quickly began to work on their current stage of the project.

As students worked on multiple various stages of the project, Mr. Thomas continued to field questions on how to use tools and machinery in the classroom. He also engaged students who were dissatisfied with their prototype because they did not manifest themselves physically as intended. One student stated, "I messed up. It is supposed to sit like that." Mr. Thomas responded, "What I can tell you to do at this point is try to get your symmetry back. You can't restart completely. Its a prototype so you can learn something." Another student stated, "My bottom is too lumpy." Mr. Thomas again responded, "That is ok. Remember this is a prototype." In the classroom, students also sought advice from their peers they worked. Students who were cutting their foam cars sought advice from students who already completed this stage. One student approached a peer stating, "I am so confused" in reference to cutting out the top view of the foam prototype. The peer, who had previously struggled with the same issue, assisted the confused peer by illustrating how to cut the top of the template to properly complete this stage.

Students worked energetically on cutting out their prototypes, testing them, and making modifications. They sanded their cars after testing. One student was noted referencing the stages of the project on the far wall to confirm the student was following

the correct process. Other students referenced the specific criteria for the project and questioned why a specific measurement had to be enforced. Mr. Thomas noted, “Because those are the rules. If I were going to build a house, we would follow the rules of design and square footage.” Students who had tested and made modifications to their car several times began to verbalize needed changes to improve their car. One student who had just completed her third wind tunnel test exclaimed, “I know what I have to do!” Another student returned to the final drawing after testing in the wind tunnel several times and noted, “I need to make it wider for my wheel size. I also need to sand it so I need to make it bigger.” Students demonstrated the ability to learn from their testing and connect this information to making changes and improvements to their car design.

As students began to complete the test and evolve stage with their foam prototypes, Mr. Thomas encouraged them to answer prompts in their design-thinking packet. These prompts assisted them in further evaluating what they learned and how it could be applied to their final car design. The first set of prompts focused on aerodynamics and asked students, “How did your design account for aerodynamics?” Student responses focused on the changes made to the prototypes: “I thought let’s make it small and weigh the least possible” and “I rounded the back and sanded it smaller.” Student responses to the second prompt on aerodynamics—”Did our redesign improve your car?”—represented a positive outlook on the changes made. Students answered, “Yes, because my drag was less when I redesigned it,” “Yes, it took off more weight, and helped my car stay steady,” and “Yes, it made it more symmetrical.” Finally, students were asked, “How do you know if it improved or hindered (hurt) your car?” One student recognized how the car was hindered and noted, “My car did become very fragile.”

Despite the fragile nature of the car, the student noted the decrease in the drag coefficient. In reference to the drag coefficient, another student answered, “I don’t know, but I guess that since it went down, my car is better.”

The second set of similar prompts investigated the thought processes of students about the weight of the car and how this impacted testing and evaluation. Mr. Thomas asked, “How did your design attempt to account for weight?” Students presented varying answers that demonstrated multiple levels of understanding. One student answered, “I made it smaller and less aerodynamic.” The student crossed out the word more and inserted less, which demonstrated some confusion in what the student was trying to communicate. One student stated, “It weighs less, so it moves faster.” Another student described making “the front flatter and middle skinnier” as changes from the original design addressed the issue of weight. A second prompt asked students, “Did your redesign improve your car’s weight?” Students provided basic answers such as, “I made it weigh less, and it helped the full car design” and “Yes because it was reduced.” Last, Mr. Thomas asked students to evaluate “How do you know if it improved or hindered characteristics of your car?” A student responded, “I think I improved it because it can move faster.” Another student, reflecting on hindrances, stated, “It may have hurt it because it was really fragile.”

Upon completion of the testing and evaluation of their foam prototypes, students had an opportunity to make a final change to their race-car designs. Mr. Thomas noted, “This is the time to make adjustments by erasing some lines on here and making final adjustments” (personal communication, February 1, 2019). He encouraged students to base these changes on the information they learned while testing their foam prototypes.

Students recorded the changes to their final design in the design-thinking packets. One student noted explicitly that they were going to "modify the top view to make the middle thicker and the back wider for the axels." Several students stated they made changes to "reduce the aerodynamic drag" and "make it faster to get more aerodynamic." One student realized the need to make changes to meet the predefined measurement criteria and "meet the height requirement." As students completed their drawings for their final design, Mr. Thomas provided the them with a lengthy 40-minute discussion about the proper use and safety when using a drill press and band saw. Students received a procedural and safety information sheet to study and reference. Upon completion of the procedural and safety discussion, students had to take and pass a safety quiz scoring 100%. Students were not allowed to operate the equipment until they achieved this score.

Once students were certified to use the power equipment, they placed their final design templates on wood car blanks and proceeded to use the band saw to cut out their cars (see wooden cut car in Appendix Q). Students measured and marked where their axels would be located and operated the drill press to complete this step. As students finished cutting out their cars, they quickly began sanding them. Students completed the final stages at varying times and rates. Mr. Thomas reinforced that students did not have time to create another prototype as they needed to proceed to cutting out their final design. He reiterated, "Learning why we don't like something is as valuable as learning about something that you do." Mr. Thomas assisted students with sanding and provided suggestions on where and how to make the car smooth. Students began to paint their cars and place them near a fan to dry quickly (see painted cars in Appendix R). Mr. Thomas called the full class over to a back table and demonstrated how to place the wheels on the

car so students could complete this task. The intensity of the student work increased as the time for completion drew closer. Upon completion of their final car, Mr. Thomas directed students to self-evaluate their work on the rubric used to grade the final car (see example of final car in Appendix S). Categories used in the rubric were design/prototyping, machining and shaping, sanding, painting, and overall appearance and workmanship.

Students had an opportunity to race their car outside of scheduled class periods. Several students signed up to race their car or have someone race their car for them. The cars were tested and raced on a CO_2-specific race track with an automatic timing device. (See race track pictures in Appendix M.) Students loaded the cars with CO_2 cartridges and Mr. Thomas placed them on the track using the proper procedures and proceeded to race each one. When the racing concluded, one student asked, "Is it too late for modifications?" (personal communication, February 21, 2019). Mr. Thomas responded, "Yes, but what would have done better"? The student responded, "sand more, make it skinner, more symmetrical." Mr. Thomas asked the students, "What did I say makes the most difference?" The students replied "weight." Mr. Thomas noted, "most cars are aerodynamically sound, but weight makes the most difference." As the students were finishing up testing, Mr. Thomas took the fastest car and measured the wheel-axle length. The measurement revealed the student did not follow the design-measurement criteria and was disqualified from winning the race challenge. Mr. Thomas quickly provided students a mathematical lesson on calculating the conversion of feet per second to miles per hour to see how fast their car was moving in relation to actual race cars. Mr. Thomas

concluded the car-racing event and design-thinking project by encouraging students to "use this process and take it toward other projects."

Elements of Design Thinking

In the next section, I explore the degree to which the core elements of the Stanford University d.School's model of design thinking were evident in the unit detailed above. I used the stages of empathize, define, ideate, prototype, and test/evolve during the coding process to evaluate the degree of absence or presence of these elements (Stanford d.School, n.d.). In addition to the stages outlined in the Stanford d.School model, the teacher of this course, added an identify stage at the start of the design-thinking process. In this stage, Mr. Thomas attempted to bring clarity and focus on the problem to be solved during the design challenge. Mr. Thomas emphasized the importance of this stage to the students at the start of the project. He stated, "We have to identify the main problem, what matters about your design, and identify what our goal is. We know our main goal is not to have a cool looking care but to make it go fast" (personal communication, January 17, 2019).

Identify. The problem to be solved for this project was to create the fastest CO_2 car. The car students created would have the opportunity to race against other cars to be named the fastest car in the seventh grade. Mr. Thomas identified and explained well this problem, and students understood, as evidenced in the classroom instruction, observations, and participant interviews. During the classroom instruction, Mr. Thomas stated, "Our is goal is not to have a cool looking car. … Our main goal is to make it go that fastest" (personal communication, January 17, 2019). Building on this primary goal, Mr. Thomas asked students to begin to think, "What does that mean?" To fully develop

the concept of speed as it relates to a car, the class discussed concepts such as traction and friction. Although Mr. Thomas stated, “zero friction would be the best solution,” he went on to explain this was not possible.

Students demonstrated their ability to identify the problem in several ways. First, Mr. Thomas asked students to write down the identified problem in their design-thinking-process packets. Students identified the problem as “Get first place with the CO_2 car,” “To make the fastest CO_2 car,” and “Make the car go as fast as possible to beat my classmates.” Although many students were able to identify the problem to be solved clearly, one student had a slightly different perspective, identifying the problem as wanting “to make the lightest and most aerodynamic car” (personal communication, January 17, 2019). Although this strategy may have produced the speed to win a race, it was not precisely the identified problem provided and identified by other students. Students identified the problem or challenge through their interviews. Emma explained, “We are working on CO_2 cars that will go as fast as we can” (personal communication, January 29, 2019). Miracle noted, “make the fastest car” (personal communication, January 29, 2019). Mark stated, “Who can make the fastest car” when asked to identify the problem Mr. Thomas provided for students to solve (personal communication, January 29, 2019). Steven explained that the focus was on what “design goes the fastest and how you would build that” (personal communication, January 29, 2019).

Mr. Thomas explained this clear identification of the problem during the first couple of classes. He “explains to them that they are going to be building a CO_2 car” (personal communication, January 11, 2019). He further clarified, “They are incorporating the design factors that are going to make it the fastest.” The precise

identification of the problem was well established at the start of this project, as evidenced by student understanding and classroom observation. Students continued to demonstrate their understanding of the problem to solve by their observed effort and improvements of their car design throughout the process to enhance the overall speed of the car. The opportunity to race their final design provided some students the ability to evaluate if they had met their goal. Although some were able to take advantage of this feedback, many students were unable to do so. The inability of all student to gain this feedback on the degree to which they addressed the identified problem was a missed opportunity. Although discussed in greater detail during the test/evolve stage of this section, the ability to see the results of the process and to evaluate it against the original problem to be solved is rewarding and key in the realization of success using the design-thinking process.

Empathize. Empathy in the design-thinking process allows the designer to develop a deep understanding of the end user's perspective, thoughts, ideas, and problem to be solved (Hasso Plattner Institute of Design, 2017). The development of empathy often occurs through direct interaction with the end user through interviews or direct observation. Empathy provides the energy and purpose to power the design process. Although Mr. Thomas briefly encouraged empathy during class observations during the research study, any meaningful or substantive evidence of its inclusion in the design-thinking-process packet, student work, observations, or student interviews was noticeably absent. Moreover, Mr. Thomas stated to the students early in the project, "We are not using the empathize step as in detail" noting the more widespread use in other grade-level projects (personal communication, January 17, 2019). He further noted the empathize

stage would be more pronounced should the project goal or problem be focused on creating cars for "fuel efficiency" or designing "safety mechanisms" for vehicles. However, students had the goal that placed them in the role of the end user. "For this project, we are looking at, Is this going to meeting your needs which is to make your car to be faster than your classmates"? Sharing the role of end user and designer can still offer some insight when engaging the empathize stage. However, a marked loss of opportunity occurred to fully and authentically develop and experience the needs and viewpoints of others. Additionally, a loss of opportunity occurred to experience the joy of creating for others and developing the social skills associated with developing empathy. Additionally, the potential energy and purpose inspired, when creating to assist others in solving a problem, was lost. This project failed to capitalize on this opportunity.

Mr. Thomas' conscious choice to avoid the incorporation of the empathize stage in this project was evidenced by the lack of related understanding of the students engaged in the project. I asked Emma how the empathy stage related to this project. She became nervous and laughed at the question. When further probed and asked if she knew the connection, she stated "No." When asked if she thinks the stage will be used during the project, she replied "Maybe" (personal communication, January 29, 2019). Further expanding empathy could be used during the final testing stage of racing the CO_2 cars. Clearly, the student was unsure of the power, purpose, and definition of the empathize stage in design thinking. Mark was able to identify an empathize stage in the design-thinking process. His thought the process provided further evidence of the absence of empathize-stage development during this project. He stated, "I was thinking about my car against other people's. I was thinking along the basis 'If their car is more aerodynamic

than mine, I have to make mine better in another way'" (personal communication, January 29, 2019). Although this line of thinking was correct and useful for this project, it did nothing to increase his empathetic skill base when interacting with others.

I asked Mr. Thomas about the absence of the empathize stage in this project. He responded, "If we were designing for the Ford Motor Company and building an actual car, we would be looking at fuel efficiency or comfortability" (personal communication, January 11, 2019). He further explained that using wooden cars with a goal of trying to create the fastest car does not provide the opportunity for end-user empathy. He noted students are allowed to create an open-ended solution essential for a design-thinking project but this project was "not as focused on empathy" as other projects. Although absent in this project, Mr. Thomas did emphasize the importance of empathy in design thinking. "It is definitely important, and I think it more important depending on what the project is" (personal communication, February 29, 2019). However, due to the time frame and main goals of this project, empathy was not fully developed. Mr. Thomas did note that developing a car to see which is fuel efficient, or maximizing passenger capacity could be used when creating cars, but not necessarily when your goal is to make the fastest car. Despite this reality, the development of a back story or creation of an end user beyond the students may have added value, designer energy, and understanding of the role of empathy in design thinking. In the future, this lack of exposure may hinder students' ability to properly implement the emphasize stage of the design-thinking process.

Define. The purpose of the define stage is to take all the information garnered during the identify and empathize stage to succinctly identify the problem to be solved

with all the necessary specific criteria that set the boundaries for design (Hasso Plattner Institute of Design, 2017). Although Mr. Thomas established the particular problem during the identify stage, the narrowing and defining of the specific design criteria was the emphasis during this design-thinking stage of the CO_2 race-car project. Mr. Thomas engaged the classroom in a full-class discussion to identify and thoroughly describe each design specification.

Mr. Thomas asked students to individually "write design criteria down that will change the outcome of your car" (personal communication, January 17, 2019). Students took several minutes to write down several specifications based on the initial discussions about the characteristics of CO_2 cars while considering how to design the fastest car. After students conferred with each other to further discuss and refine, Mr. Thomas encouraged them to write the specification they thought would be most important while designing their cars. Mr. Thomas methodically reviewed the list of specifications such as gravity, weight, friction, traction, and aerodynamics. In addition to the list of specifications and design criteria that would impact the speed of their car, Mr. Thomas provided a list of specific measurements that limited the height, length, width, and wheelbase of the car.

The process of narrowing design specifications is often informed by interactions with the end user and information gained during the empathize stage. In this project, the specifications and design criteria were partially predetermined for the students. The lack of a fully authentic empathize stage during the project forced students to rely on their limited knowledge of CO_2 cars and predetermined measurements. The predetermined nature of this process was apparent to students. Mark described the define stage as "he

tells you what you are doing" (personal communication, January 29, 2019). Miracle shared a similar point of view noting, "He had regulations about it has to be so wide or so long" (personal communication, March, 14, 2019). Despite the lack of a fully authentic define experience, one student confirmed the positive influence the define stage had on their final design. Emma stated that the define stage influenced her thinking about how to design her car. She thought, "I'm going to do it this way, and then I heard some rules, oh, that isn't going to work, change it up a bit" (personal communication, January 29, 2019)

Mr. Thomas explained that, due to the technical aspect of the CO_2 cars, it is essential that he describe how the car works. He noted, "They then have to know how to design a car well" (personal communication, January 11, 2019). Although he acknowledged the define process was somewhat restrictive, students were open to creating as they desired within those limitations. Mr. Thomas saw this stage as extremely important, "so they can define the problem" and make wise design choices, which is "valuable in the end" (personal communication, February 28, 2019). He also noted how much he was "amazed at some of the different things they think of" when participating in the define activity. The define stage of this project provided adequate information for students to plan their design. However, the lack of information developed during the empathize stage negatively affected the full development and exploration to define the specifications of the problem independently.

Ideate. The judgment-free brainstorming of possible solutions is the hallmark of the ideation phase of design thinking (Hasso Plattner Institute of Design, 2017). The ideation phase of the project provides ample opportunity for students to brainstorm in a free and open manner. Mr. Thomas explained to the class that the ideate phase "starts to

get the ideas flowing." Students were provided physical models from which to stimulate ideas. Additionally, students were encouraged to use Google images of CO_2 race cars for inspiration about possible solutions to the defined problem. Mr. Thomas affirmed the importance of this stage of the design-thinking process. "Today is the day the winner of this class is going to be decided. Now how can I say that?" A student replied, "The winner has to have their car planned out properly." Mr. Thomas responded, "If you don't have a solid plan of attack, you are not going to have the fastest car" (personal communication, January 21, 2019).

Mr. Thomas created a rich atmosphere of judgment-free brainstorming. For example, he stated, "There is no such thing as a bad idea. This is your basic first try at getting some basic ideas on paper. This isn't your final design yet" (personal communication, January 21, 2019). The brainstorming of various solutions was also evident through student questions. One student engaged Mr. Thomas in a discussion about using three wheels instead of four. Although Mr. Thomas explained why this was not possible, he did state, "That is a very thoughtful question. I like that you are thinking." To ensure students were immersed in the ideation process, students were required to draw a total of eight different cars showing the top and side view of the design.

When interviewed, students confirmed the use of Google Images to find cars they thought might provide the desired design. Steven shared, "A lot of us at first were researching and trying to find out what the best designs would be for our CO_2 cars" (personal communication, January 29, 2019). When asked about how she engaged in the ideation stage, Emma noted, "We had to just think about some of the factors the

incorporated into them. I was just thinking over and over again" (personal communication, January 29, 2019). She further explained that she began to put the ideas from her head to paper to create several possible designs. Miracle reported she developed ideas by "looking on other examples" (personal communication, January 29, 2019). Mr. Thomas provided several finished examples of actual CO_2 race cars completed by other students. Miracle and other students were observed viewing several of the models. Miracle noted that with all the requirements established in the define stage, one had to be "strategic" in thinking about possible designs. Steven conveyed a similar sentiment noting, when thinking about all requirements, it was "difficult but it really helped me a lot" (personal communication, March 14, 2019). Once they had ideated eight cars, Mr. Thomas required them to pick one design to choose as the final design to sketch on graph paper.

Prototype and test/evolve. Prototyping takes the models developed during the ideation phase and brings them into the physical world (Hasso Plattner Institute of Design, 2017). This stage often provides designers with the ability to gain information about what can be changed or improved before creating a final solution. Mr. Thomas seamlessly integrated the stage of prototyping into the project following the ideation stage. He required students to take their final ideation sketch and transfer it onto a full-size pattern sheet. He required precision and detailed drawings rather than free-hand sketches. After creating an exact pattern, students copied the design, cut it out, and glued it to a foam block. Students cut out the foam block following the model created. Mr. Thomas reinforced, "This is just a possibility" and not the final design of their car

(personal communication, January 23, 2019). While completing their prototype, I often observed students discussing and checking measurement specifications.

Immediately following the creation of the prototype, students began to test and evolve their prototype. Testing allows the designer and others to interact with the prototype to provide feedback to improve the design (Hasso Plattner Institute of Design, 2017). Mr. Thomas first provided students a baseline of weight and drag measurements. Mr. Thomas stated, "If you don't have that baseline to compare against, then you are just going to guessing If your prototype is good or not" (personal communication, January 25, 2019). Steven explained further, "We weighed and tested the aerodynamic drag" of the first version of their car (personal communication, January 29, 2019). Students then began to make changes to their cars to improve the drag and weight.

As students began to make changes, they engaged in an iterative process of testing and evolving their prototypes. Using the data from the wind tunnel and scale, they were able to make decisions about how to modify their design. I observed students sanding, discussing how to improve their cars with peers, and returning to the foam cutter to remove sections of their cars. The engagement level and focus of the students during these stages was extremely high. Mark noted, "I took the knowledge that I got and wrote it down. I put it into my wooden car" (personal communication, March 14, 2019). Mr. Thomas expressed the importance and power of the prototype and design stage on the students.

> As I watch the kids build a prototype and test it and see the data, and really think deeply about what their design is going to look like and compare to others—if

they had not prototyped, they would have missed a whole lot of deep thinking. (personal communication, February 28, 2019)

The strength of the CO_2 race car project lies in the test and evolve stage. The creation of a foam prototype, testing using the wind tunnel and scale, and the modification and retesting allowed students to engage in an authentic design-thinking process fully. The actual testing of the wooden race cars using CO_2 powered canisters provided further evidence of the testing stage of design thinking. Although most students were unable to participate, one student realized the power of this final testing phase and asked, "Can we make more modifications" (personal communication, February 21, 2019). Although the opportunity to make additional changes passed, the question reinforced understanding of the possibilities of the prototyping and test/evolve stage.

Benefits and Limitations of Design Thinking

In evaluating the data from this study, I also examined the possible benefits or limitations of design thinking specifically to classroom instruction and student learning. The data revealed several examples that supported the conclusion of benefits and limitations. The opportunity to develop skills necessary to engage in the Fourth Industrial Revolution environment, the inclusion of multiple core curricula, consideration of instructional time frames, and the transference of design-thinking skills arose as significant themes I will discuss in the section that follows.

Fourth Industrial Revolution Skills and Design Thinking

Researchers have touted design thinking as a process with the possibility of developing the skills necessary to engage in the Fourth Industrial Revolution. Although research in this area is not fully developed, this study provides some pertinent findings

surrounding this possible outcome. Students who participated in this unit showed evidence of developing skills such as collaboration, the ability to solve complex problems, and knowledge of data analysis. Additionally, students strongly endorsed the benefits of hands-on learning activities. The structure of the classroom and project provided students an opportunity to engage in activities that created an interactive learning space for these skills and challenging the common linear model of middle school education.

Collaboration. The ability to collaborate with others while solving complex problems is an essential skill employees will need to possess in the Fourth Industrial Revolution (Doucet et al., 2018). Various examples of collaboration emerged among students while creating their race cars. Several times during the project, Mr. Thomas asked the students to pair with another peer to review their work and provide feedback. These activities offered varying levels of collaboration among students. During an exercise to define the problem to be solved, Mr. Thomas asked students to discuss their created list of criteria and challenge each other about the content of their lists. Students quickly engaged in vibrant discussions surrounding the requirements established by the students. In contrast, Mr. Thomas asked students to share their final sketches with a peer for critique and review. During this collaborative activity, I noted little feedback and limited participation. Mr. Thomas also strongly encouraged students to observe the analytics of their peers during the testing phase of the project. He emphasized that by observing others' data, students may be able to learn about what to change on their race car. He referred to this type of collaboration as "covert collaboration by watching and

paying attention to what is going on in the class" (personal communication, February 28, 2019).

I also observed naturally occurring collaboration among students during the class sessions. I saw a male and female student discussing the structure of their cars while working at a side table. One student shared, "I am concerned the front end of my car is going to break." In response, the other student cautioned, "Remember, you have to sand it" (personal communication, January 21, 2019). The conversation continued between the two students providing feedback and reminders about specifications that needed to be considered. Another example of spontaneous collaboration among students involved a male student seeking direction from a female student who was further along in the design process. A student approached Emma inquiring about how to find the line of symmetry, stating, "I need your words of wisdom." Emma responded, "I would find the line of symmetry by finding 7/8th inch and mark it down" (personal communication, January 23, 2019). Emma took a pencil and marked the measurement for the student. Further discussion occurred between the two about the best way to measure to ensure accuracy. Similar conversations among students during the design process occurred daily. Mr. Thomas encouraged these naturally occurring collaborative conversations, often reminding students to ask each other for assistance and discuss their designs for feedback from peers.

The opportunity to employ and practice the skill of collaboration was ample during the project, supported by the prescribed activities developed by Mr. Thomas and the natural classroom environment created to design cars. Emma noted, during her interview, "You could talk to someone about their design, and then you can help each

other design" (personal communication, January 29, 2019). Steven shared, "Sometimes it's just like as simple as you don't understand like what something means, and you just explain that to somebody" (personal communication, January 29, 2019). Steven further shared that his experiences with collaboration during the project led to the improvement of his car. Steven noted students would make comments such as, "this little section you might want to fix." Although students had opportunities and were encouraged to collaborate, they did so while working on their own individual project. The structure of individual projects limited the degree to which students were able to collaborate. If students had the opportunity to work together on creating one race car, is distinctly possible that the opportunity and need to collaborate in a deeper fashion would have existed. Although the data included the presence of collaboration, the student groupings presented a missed opportunity to create a richer collaborative environment.

Solving complex problems. Design thinking is a potential strategy to effectively engage wicked problems, which are ill-defined, challenging problems with multiple possible solutions (Carroll et al., 2010; Koh et al., 2015). The skills to engage complex problem solving will be essential for those learning and working in the Fourth Industrial Revolution. The results of this study provided evidence of students attempting to understand and solve a complex problem. The complex problem required them to decipher and apply technical knowledge to a possible solution. Additionally, from this struggle, various and multiple solutions emerged. Students experienced failure on a consistent basis, which they learned to apply to their solution. While attempting to solve the problem of designing the fastest CO_2 race car, a student defined the design process as "hard." Mr. Thomas reinforced this statement and noted, "The design process is not

always easy" (personal communication, January 23, 2019). The struggle students experienced was evident throughout the design process.

The stage of transferring the top view paper template to the foam block was representative of the critical thinking and problem-solving struggle students experienced. Emma faced difficulty in understanding how to properly place the top view of the template design sketch on the foam block prototype. The student realized the template did not fit and after some discussion with Mr. Thomas, he cut the template in half. Emma exclaimed, "You cut my care in half. I am confused!" Mr. Thomas stated, "I want you to problem solve a bit." Emma responded, "It is still not right. I am so confused. I don't understand it!" (personal communication, January 23, 2019). This exchange was typical of the struggle students experienced when working through the various stages of designing their cars. Although students eventually were able to arrive at a solution, the need to struggle and think critically was evident. Mr. Thomas noted the importance of engaging in this struggle, especially "as young kids as they move forward and the content and problems get harder" (personal communication, January 11, 2019).

The unraveling of a problem that has multiple solutions is a hallmark of a well-constructed design-thinking project (Brown, 2009; Carroll et al., 2010). Although Mr. Thomas provided students the exact same problem to solve with predefined criteria, students created multiple and varied solutions. From the start of the project, Mr. Thomas encouraged students to develop multiple solutions to the complex problem. Mr. Thomas assured the students, "There is no such thing as a bad idea" (personal communication, January 21, 2019). Students were required to develop many ideas that may have served as a solution to the problem. When students questioned the need to develop multiple

solutions, Mr. Thomas responded, “If you were going to build a house, would you build the very first house you see?” (personal communication, January 17, 2019). The students began to understand the need to create multiple solutions to create the fastest car possible. Emma described this process as “just thinking over and over again” with “ideas just popping into my head” (personal communication, January 29, 2019). Miracle noted, “It was kind of fun seeing what you can do, and the different types of ways there can be outcomes” (personal communication, March 14, 2019).

The process of creating multiple solutions to a complex problem encourages students to think through and design a well-developed solution. Mr. Thomas stated the push to develop multiple solutions was to “design things that are outside the box” (personal communication, January 11, 2019). He went on to explain the importance of creating complex projects with multiple solutions. “I think it is important to have those times where their solution can either be met in a number of different ways. The process is just as important” (personal communication, January 11, 2019). The opportunity to practice and obtain skills to engage in complex problem solving with multiple solutions was well represented in this study.

Technical knowledge and concepts also frequently align with solving complex problems. In this project, Mr. Thomas provided students with precise guidelines and technical knowledge. He provided the technical knowledge of how CO_2 operated before they began to design. Students further discussed the technical aspects of the shape, weight, size, and aerodynamics. Additionally, Mr. Thomas provided technical elements and requirements for the design of the car. Steven noted, “The most difficult part was doing the full-size design because that’s when you need to be to be really careful and

meticulous" (personal communication, January 29, 2019). The need to understand and incorporate the technical knowledge provided a further challenge and opportunity to engage in future-ready skill development.

Data analysis. The evaluation of technical data is another skill needed to effectively engage in the Fourth Industrial Revolution (Doucet et al., 2018). Students engaged in an extensive opportunity with data during the design process of their race cars. Specifically, students each had the opportunity to measure the drag coefficient and weight of their prototypes an compare the analysis of these data to the baseline data provided. Mr. Thomas cautioned the class, "If you don't have that baseline to compare against, then you are just going to be guessing" (personal communication, January 25, 2019). I observed students testing their prototypes, comparing their data to the baseline and to previous tests. This data evaluation triggered students to construct observations and implement changes to their cars. A student noted after a trial, "Went down one. How do I modify this to make it better?" Mr. Thomas replied, "I am not going to tell you how to redesign. There are several things you can do." Mr. Thomas encouraged students to evaluate their data in comparison to their and other cars to make the changes necessary to improve the speed of their cars.

Emma shared her thought process for evaluating her data. "We did a bunch of testing and weighing and then a lot of us were busy trying to reweigh and retest the drag" (personal communication, January 29, 2019). Emma further explained how the testing and data would inform the decisions to make the care lighter or more aerodynamic. Miracle supported the benefits of testing and data analysis remarking, it "was helpful because it gave me time to figure out what I needed to change, and it helped me modify

the prototype" (personal communication, March 14, 2019). As students had the opportunity to engage in data collection and analysis, they were able to practice this essential and critical skill.

Learning from failure. During the development of race cars, I observed students experiencing multiple opportunities to experience failure: when sketching car ideas, drawing final sketches, cutting out foam prototypes, and testing their cars. Mr. Thomas encouraged students to take chances during the design process, which promoted increased opportunities to experience failure. For example, he stated, "I need you to start thinking what do I need to change? You have nothing to lose!" (personal communication, January 25, 2019). As a result, I observed students engaging in risk-taking behaviors often during the prototype phase. Mr. Thomas further noted to the class, "I need to see you fail. I need to see you flounder. I need to see you make bad choices." Mr. Thomas was observed consistently encouraging students throughout the study to make changes or choices that were not guaranteed to work.

The creation of this culture of accepting failure was the foundation for the learning Mr. Thomas desired. He explained that the purpose behind the risk-taking and failure was "not just teaching content, but teaching them skills they need to be successful" (personal communication, February 28, 2019). The ability to engage in failure allowed students to experience, develop, and practice skills of persistence and grit. Miracle noted, "Failure made me and helped me if something did not go right. It helped me fix it and not be upset. Just keep on trying" (personal communication, March 14, 2019).

Hands-on learning. The creation and design of a race car naturally encouraged and supported many hands-on activities. Students had opportunities to sketch, trace, cut out foam prototypes, and cut and paint a final car made of wood. As students experienced the opportunity to engage in developing skills necessary to participate in the Fourth Industrial Revolution, students strongly endorsed the ability to engage in hands-on learning. Miracle stated that she finds most classes to be "boring" but hand-on projects are "kind of fun" (personal communication, March 14, 2019). Mark shared, "When we started working with our hands, I was kind of happy" (personal communication, March 14, 2019). Steven confirmed the enjoyment of using his hands to learn. He noted creating a prototype was fun "because it is, and once you have a foam block, you can actually do something with it. You're actually seeing how the process works" (personal communication, January 29, 2019).

The students further expanded on the beneficial aspects of hands-on learning in the classroom. Steven shared that sitting in a traditional classroom is like being "spoon-fed," but hands-on learning allows a student to experience and "try to learn by yourself" (personal communication, January 29, 2019). He further expanded, "I can sit there and keep writing and writing, and then I can learn it, but I won't fully understand it. But, when I do it with my hands, I'll automatically get what we are talking about" (personal communication, March 14, 2019). Mark shared a similar opinion: "Whenever I am working with my hands, I understand it better than sitting there and writing it down" (personal communication, January 29, 2019). The viewpoints and opinions of these students directly align with the constructionist theory underpinning design thinking. The central tenet that learning occurs when students begin to create with their hands supports

the student experiences in this study. Additionally, Eccles and Roeser (2011) noted the detrimental and inhibiting didactic model of schooling. Steven stated "A lot of times what will happen is the teacher will just show you stuff and then you're like 'oh ok.' But then you don't actually comprehend what you are doing" (personal communication, January 29, 2019). The incorporation of hands-on activities, such as the ones used into this design project, assist students in learning through a more student-centered and open learning environment.

Core-Content Integration

Researchers of the use of classroom-based design thinking have reported various results surrounding the ability of teachers to integrate core content (Apedoe et al., 2008; Kramsky, 2017; Kwek, 2011). Although some found it to be challenging, others found natural and logical connections. The findings from this study revealed the purposeful and successful integration of the core content areas of mathematics, science, and art into a design-thinking unit. Although Mr. Thomas successfully integrated these areas into the design-thinking project and process, I noted some barriers to their full implementation.

Exposure to science content was significantly present during classroom instruction. The class discussed scientific concepts when conversing about how to power and design the fastest car possible. Mr. Thomas explained the process of how CO_2 race cars are powered. He then asked the students, "Where do we find CO_2 "? A male student replied, "In the atmosphere." A discussion occurred about where CO_2 occurs and how it can power the race cars. Additionally, Mr. Thomas integrated scientific laws into the classroom instruction. Mr. Thomas, during instruction on motion, stated, "The law we are focusing on is Newton's law of motion, equal but opposite reaction" (personal

communication, January 17, 2019). Mr. Thomas and the students frequently used other scientific terms such as traction, friction, drag, gravity, force, resistance, and aerodynamics during instruction and class work. When Mr. Thomas asked students for a definition of aerodynamics, a student responded, “Aerodynamics is, I guess, the resistance of something … the air coming on the car on the front”. Mr. Thomas replied, “Exactly, it is the study of a body, person, car, or rocket moves through the air” (January 17, 2019).

In an interview, Mark referenced the term aerodynamics several times. When asked to elaborate on the importance of aerodynamics, he shared the following. “If you have little aerodynamics, then it will cause little drag. So, it will cause your car to go faster” (personal communication, January 29, 2019). Steven shared, “We also learned about more things about drag and weight and how that can affect stuff” (personal communication, March 14, 2019).

Mr. Thomas also integrated mathematics content into the unit. He asked students during this project to use the metric system to measure the length, depth, and width of their race car. Mr. Thomas stated, “In the beginning students will learn some basic measurement skills, knowing they will need to take measurements as they go through the process of building the car” (personal communication, January 11, 2019). He further noted that students often enter his classroom with varying levels of understanding of measurement. The intentional instruction of measurement occurred through several methods during the project. A full-class discussion occurred during the first class session to stress the importance of measurement to this project. Mr. Thomas asked the students to think, “Why are we using measurement”? A student quickly answered, “We don’t want

our car to be lopsided" (personal communication, January 17, 2019). Mr. Thomas also introduced a computer game focusing on measurement skills directly related to their project. Students practiced measurement skills by playing this computer game each day as their opening class exercise.

In addition to the basic instruction on measurement, students engaged in mathematics while creating their prototypes for their race cars. Students used scales to measure the weight of the cars, a wind tunnel to determine a drag coefficient, and rulers to measure the specifications of their race car. Students would often engage Mr. Thomas in discussion related explicitly to measurement using the metric ruler. For example, one student inquired about if they were to measure the length of the race car in "inches or centimeters?" (Personal communication, January 23, 2019). Mr. Thomas asked the student to think about "How many millimeters were in a centimeter?" After some discussion, the student was able to make the proper conversion to determine and measure the correct length of the car. When asked during student interviews to identify core content students learned during the design-thinking project, Miracle noted that the mathematics content "helped me with my measurements" (personal communication, March 14, 2019). Steven shared that he learned "more things about drag and weight" and how these affect the performance of his race car (personal communication, March 14, 2019).

Students also had opportunities to engage in art content during the lesson. Mr. Thomas asked students to sketch several race cars during the ideate phase. Mr. Thomas provided coaching for those students who desired individual instruction on developing these skills. During the final sketching stage, Mr. Thomas required students to use rulers

and French curves to create an exact drawing to be used with their foam prototype. Additionally, students had creative liberty to create the shape and color of their car.

Mr. Thomas noted the importance and benefit of integrating various content areas into this project. “I think there is a huge overlap between how we could take some of those pieces and tie them together” (personal communication, January 11, 2019). The purposeful daily measurement activities, instruction, and consistent use of scientific principals with students throughout the project supported his statement. Mr. Thomas further pointed out that the exposure to various aspects of engineering, mathematics, and art guide students in future educational or employment pursuits. “They find out what they like. What they don’t like. I think that’s definitely valuable” (personal communication, January 11, 2019). The integration of other content areas in the design-thinking process provides an opportunity for educators to meet the requirements of their core standards while reinforcing standards whose primary responsibility lies elsewhere. This reinforcement benefits the students by providing engagement of academic content in various contexts. Despite the potential for benefits of cross-curricular integration, the “struggle with timing” and pressures of covering one’s own content standards provides constraints on how effectively or intensely this can be accomplished. Mr. Thomas noted the potential exists, but the limited amount of time does not “allow for a whole lot of cross-curricular” (personal communication, January11, 2019).

Time

Although an unlimited or extended amount of time to cover content is the desire of most educators, the issue of time constraints based on scheduling provides a barrier to the desire to expand the content and experiences of the instruction. Earlier research noted

time provided some constraints to the implementation of design thinking (Retna, 2016; Kwek, 2011). Mr. Thomas noted, “That is probably the thing that I struggle with the most as far as there’s a lot of depth that we could achieve in this area” (personal communication, January 11, 2019). Mr. Thomas explained further his affinity for middle school exploratory classes but “at the same time you feel a bit handcuffed because you want to go deeper, but you really don’t have that option.”

Time constraints to deliver content was a theme evident throughout the study. During the first class period, Mr. Thomas informed the students, “By the time we design, prototype, and build a CO_2 car, we are going to be scrambling to try to get it done. It is going to take longer than you think” (personal communication, January 17, 2019). When he asked students what would make the project better, a student responded, “time” (personal communication, February 27, 2019). Students explained how they desired to use the information from racing to redesign their car to make it faster. The disruption and loss of class time due to weather-related cancellations and delays further exacerbated the issue of time.

Although the issue of time constrained the perceived depth of instruction and ability of students to complete as many prototypes as desired, evidence of a substantial design-thinking project with meaningful curricular connections was evident. Students took part in significant academic discussion involving technology, engineering, mathematics, science, and art content. Additionally, students were able to create prototypes that they could test several times before building a final car. Although some students may have been forced to move through some stages sooner than desired, the experience was rich with content and activity, which created an active and expansive

learning environment. Mr. Thomas noted, “We do spend quite a bit of time prototyping to get them to their final solution” (personal communication, February 28, 2019). The time spent on this stage allows students to engage in the iterative process of design thinking in a meaningful way. If given the opportunity, increasing the amount of time allotted would increase the opportunity to redesign cars after the final step. Mr. Thomas noted he “liked the idea that it would be cyclical” and students would be able to process the data and information learned to create a faster car.

The Understanding and Transfer of Design-Thinking Skills

Mr. Thomas provided the design-thinking process as a framework from which students would solve the problem of making the fastest race car. Mr. Thomas introduced the design-thinking process and the associated steps briefly at the beginning of the project. Students received a design-thinking packet to support their understanding and guide them through the design-thinking process, along with the associated project steps. During the initial stages of the project, Mr. Thomas encouraged students to look at the design-thinking icons on the front of the packet. He further explained to the students that design thinking is “a really nice way to keep you on track when you are trying to solve a problem” (personal communication, January 17, 2019). When asked to further explain the purpose and goal of the packet, Mr. Thomas explained the “logic behind the packet is really that the kids sort of know the step they’re going through as they progress through the project itself” (personal communication, February 28, 2019). Mr. Thomas further explained that although he may not provide direct instruction that goes into great depth at each stage, students would have an awareness of how the design-thinking process, if used in other classrooms.

The absence of in-depth instruction on the stages of design thinking was evident during the student interviews. When asked to identify the specific process being used to solve the presented problem, students were unable to identify the design-thinking process independently. Emma shared, “we need to do a bunch of prototyping” but failed to identify the design-thinking process stages by name (personal communication, March 14, 2019). Additionally, Emma noted that the stages of design thinking created some confusion and what precisely to do in each step. Students provided similar responses when I asked them to identify and explain the process used for design. Despite not being able to identify the design-thinking process, students were able to identify some of the stages of the process and how they related to the project. Students noted the importance of ideation and creating ideas for cars so they could understand what it may look like. Steven shared that he used prototyping “to find out what would be well suited to make or build” (personal communication, March 14, 2019).

Mr. Thomas acknowledged the superficial use of design-thinking terminology. The limit of time spent on discussing the specific steps of design thinking allowed for the majority of the class time to be spent engaging in the hands-on activities. Although this format was beneficial in one aspect, the lack of in-depth instruction of the design-thinking process may limit skill transferability. Students engaged in activities during the project that directly correlated with the specific steps. However, they received little reinforcement or instruction that connected the well-designed activities to the particular design-thinking steps. This absence provided students with a basic understanding of the design-thinking process. The absence of the students’ ability to accurately identify the

process and the steps associated supported the concern of transferring the skills to other problems outside of the project.

Summary

In this study, I examined three questions to better understand the possibilities of design thinking, evidence of the presence of the design-thinking stages, and barrier and limitations to the implementation in a seventh-grade technology-education classroom. A teacher implemented a design-thinking project, creating CO_2 race cars, in a seventh-grade technology-education classroom. The project, using the Stanford d.School model of design thinking, had students define a problem, brainstorm possible solutions, and create a prototype, while testing and making adaptions before creating a final car. Although many of the stages of design thinking were well represented, the lack of the empathize stage was evident. The missed opportunity to fully develop the empathize stage negatively affected the ability of students to independently define the parameters of the problem to be solved.

Although the empathize and define steps were not entirely authentic, the ideation along with prototyping and testing stages provided students with engaging and realistic experiences surrounding design thinking. The possible positive outcomes associated with the use of design thinking were the opportunity to engage in practicing and learning future-ready skills, and effective inclusion of various core content areas during instruction. Although time limitations can present concerns with full engagement in the design-thinking process, the project provided evidence of effective and meaningful exposure to the design-thinking process. Finally, the lack of specific identification of the

design-thinking process by students created concern about their ability to transfer the skills to future problem solving.

Chapter 5

Discussion

The purpose of this qualitative case study was to provide empirical evidence of the use of design thinking in a K–12 classroom. I evaluated the stages of design thinking to determine the presence or absence of design thinking. Further analysis entailed examining to what degree the stages impacted the design-thinking process. Finally, in this study I explored the possible benefits and limitations of implementing design thinking in a K–12 classroom. This chapter includes discussion of the findings related to the implementation of design thinking in a K–12 setting, implications for school districts and educators, realized benefits and limitations of design thinking, recommendations for future research, and examination of the study limitations.

Design Thinking in Action

The lack of empirical evidence of the implementation of design thinking in schools is well established in the literature (Davis & Littlejohn, 2017). One primary purpose of this study was to provide a detailed example of the use of design thinking in a K–12 classroom. Study results provided a comprehensive example of how one teacher created an effective project using the design-thinking process. The teacher was able to successfully implement a unit on creating CO_2 race cars, evidence by the data. First, he made a deliberate decision to use the design-thinking model as the central academic basis for the unit. Each of the steps used to create the race cars closely aligned with the design-thinking process. For example, the teacher required students to develop ideas for their race cars. As a result, Mr. Thomas used the stage of ideation to create activities that used the principles of this stage. He required students to brainstorm, with no judgment, as

many possible cars that may provide a viable solution. Additionally, during the prototype phase, students created actual foam race cars from their chosen race-car designs. Students were then able to test those prototypes to improve on the design. The connection of the activities in the unit to the specific design-thinking process allowed for deep connections and successful implementation of the process.

The creation of packets also supported students in design thinking during this study. The packets provided a clear visual representation of and connection to design thinking for each of the stages. Additionally, Mr. Thomas required students to record information and encouraged them to think critically and reflectively about how each stage impacted the design-thinking process. I also observed purposeful instruction and discussion of the design-thinking process during class sessions. The instructor took the time at the beginning of the unit to briefly review the design-thinking process. He further discussed how this process was essential and how it might be used in future problem-solving. Throughout future class sessions, students learned of connections to the design-thinking process through small group or individual teacher discussions.

This study fills a critical gap in the literature by providing evidence of how teachers might implement design thinking in middle grades classroom settings. Although the limitations of a case study conducted in a unique setting make generalizations impossible, this study provides a comprehensive example from which other professionals can build their future practices. Educators can begin to conceptualize the use of design thinking, moving from the theoretical to the practical. Scholars advocate the need for research in design thinking in education, to create a collection of best practices (Carroll et al., 2010; Davis & Littlejohn, 2017). This study provides evidence of the use of design

thinking in a K–12 setting, offering the distinct possibility of creating some best practices for the implementation of K–12 design thinking.

Implications for K–12 Implementation

The implementation of design thinking in schools has the possibility of moving schools from a place of traditional fact-based instruction to schools that foster skills where students think critically, collaborate, and obtain a greater sense of agency (Burdick & Willis, 2011). This study revealed several themes that are worthy of consideration for educators seeking to implement design thinking in the classroom. The question, "How is this possible?" may be a common concern among educators who face limited time, demands of content coverage, and preparation for standardized testing. This study offers some guidance on how educators might navigate these concerns and still promote design thinking.

As educators embark on the implementation of any new teaching strategy, professional development is essential. This study demonstrated the impact of the vast amount of professional development the instructor received before he created and implemented a success design-thinking project. Initially, the instructor noted he had experienced a basic level of a design process that he learned in college and then used at the start of his career. Upon entering his current district, he received an hour of monthly professional development focused solely on the design-thinking process. The professional development subdivided the design-thinking stages and provided instruction on how to engage students during each stage. He noted that during this professional development, the creation of unit plans to implement design-thinking projects was part of the process.

Before the implementation of the design-thinking project implemented in this study, the instructor had spent 3 years involved in this professional-development course.

For school districts to fully support teachers and create environments of successful design-thinking implementation, educators must receive substantial and quality professional development. This study provided an example of an exemplary implementation of design thinking. However, the proficiency of the teacher can be partially attributed to the vast amount of professional development provided. School districts and administrators need to be prepared to provide a similar experience for teachers who desire to engage in design-thinking instruction. Kwek (2011) supported the essential need for teachers to invest and learn about design thinking in order to proper employ design thinking instruction. The complexity and specificity required to properly implement design thinking requires a full commitment to comprehensive and sustained teacher professional development for successful implementation.

Second, the ability to successfully integrate core content in the design-thinking process has proven difficult for many educators (Kramsky, 2017; Kwek, 2011). Although researchers support some successful attempts to integrate core content standards into the design-thinking process, they reported many barriers to consistent implementation. Such barriers are the pressures of covering core content and standards while being held accountable for standardized test scores, difficulty coordinating the goals of design thinking and content, and reluctance to teach core content in a nontraditional teaching environment and format (Apedoe et al, 2008; Retna, 2016). Scholars have called on researchers to examine effective ways to integrate core curriculum into design-thinking instruction (Carroll et al., 2010).

This study answers this call for further research and provides one example of how teachers might teach core content through design thinking. Each day, Mr. Thomas asked students daily to engage with mathematics and science concepts to properly design their cars and attempt to make them aerodynamic. Most importantly, the mathematics and science core content addressed were naturally connected to the project. For example, students created cars with specific measurements. As a result, the instructor provided mathematics-specific content lessons that fostered the necessary skills for students to accomplish this task. Students engaged in measurement computer games to increase their measuring abilities. Further, students discussed the metric system and conversions between measurement standards. Upon completion of racing their wooden race cars, Mr. Thomas instructed students on the proper conversion of feet per second to miles per hour.

Students needed to understand basic scientific principles to create and improve their car's design and speed. As a result, the instructor integrated scientific concepts into the lessons as needed, which naturally fit the goals of the project. For example, students discussed the need to consider how aerodynamics played a role in creating a fast race car. As students designed, tested, and modified their cars, they consistently examined shape aerodynamics. The instructor also effortlessly integrated laws of motion, traction, and friction into the project and lessons. Students received minilessons on sketching and drawing, which introduced art-related content. None of this attention to core content was forced or contrived but rather served a specific purpose in the completion of the project.

This study suggests that one solution to the concern of integrating core content into design-thinking projects is to look for natural connections already present in the project. Attempting to force activities or introducing content outside of the primary

standards may cause dissonance and confusion among students, thereby decreasing learning. Instructors seeking to integrate core content effectively must search for logical meaningful connections and then create activities that integrate content effectively into the design-thinking lesson. This logical connection allows for the creation of well-designed and meaningful activities, which in turn should lead to the understanding and learning required for specific content and standards.

Study finding also suggest that no perfect project or lesson exists when using design thinking. Although some projects may create plentiful opportunities to engage in some aspects of design thinking, they may also fall short or provide less opportunity for engagement in others. Educators must evaluate the potential of each project in developing students' skills relevant to the different elements of design thinking. The results of this scholarship provided an example of a well-developed design-thinking project, but one that also was limited in some stages of the design-thinking process. The empathize stage in this study was somewhat limited, which removed the possibility of students being able to engage in understanding the needs of an end user. Empathy is an essential component in order to activate the human-centered aspects of design thinking (Carroll, 2014). A lack of information students could have gained through interaction with an end user further limited the data students were able to analyze and integrate during the ideation phase of this study. The students did not have the opportunity to think about the needs, desires, or requirements of an end user. Instead, they were forced to design for themselves. Although this format provided some limitations, students were still able to engage in a level of rigorous ideation.

Following the ideation stage, this study documented students deeply engaging in the prototype, test, and evolve stages. These stages of the design-thinking process were stronger than the stages mentioned earlier. Students spent a significant amount of time thinking, creating, mentally struggling, and benefitting from creating foam prototypes, testing them, and making informed decisions to modify their designs. The lack of parity and quality among the stages did not hinder or affect the overall ability of students to engage in the design-thinking process. Every project is likely to have stages that are stronger or better developed than others. This variance should not discourage educators from attempting to implement a lesson or project using design thinking. Educators simply need to clarify their goals for students and evaluate the degree to which given projects will help them advance these goals. Additionally, as educators implement projects, they continue to have room for redesign and improvement to strengthen the various stages and activities to provide a richer experience for students.

Potential Benefits of Design Thinking

Scholars have argued that students need to engage in learning activities that promote the opportunity to develop skills necessary to effectively engage in the Fourth Industrial Revolution (Koh et al., 2015). These skills include critical thinking, collaboration, data analysis, flexibility, and the ability to engage in complex problem solving (World Economic Forum, 2018). For educators to teach these skills successfully, schools, which tend to be didactic and traditional in nature, will need to change their approach to instruction (Koh et al., 2015). Schools need to provide experiences for students that promote agency, are open-ended in their solutions, induce critical thinking, and encourage collaboration with others. The evidence produced from this study suggests

that these crucial skills can be developed through the use of an instructional method centered in design thinking.

Students in this study received several opportunities to engage in critical thinking. Initially, the instructor asked the students to define the problem or think about how a CO_2 car operated, concerning speed. Students were forced to think about the many physical and scientific concepts that may affect the speed of the car. Concepts such as traction, friction, and aerodynamics demanded that students consider how these factors interrelated and affected the speed potential of the car. Students further engaged in critical thinking while ideating various car shapes and models to solve the proposed problem. Additionally, critical thinking was evident as students tested their foam prototype cars. Students examined the data and then decided if changes were required to improve their model.

As a result of the activities and classroom environment, students engaged in collaboration at varying levels with peers throughout the study. Collaboration, while students were working on their projects, was often spontaneous and authentic. For example, I observed students talking about their car designs with their peers while working on sketching models or modifying their prototypes. Students focused on gaining specific feedback, asking questions about specifications, or discussing their thought processes for their choices verbally. Although this category of collaboration provided productive conversations, some students simply collaborated during this time to receive instruction about how to complete the next step of the process or understand specific requirements for design.

Examples of structured collaborative experiences occurred when directed by the instructor. Mr. Thomas asked students to share their viewpoints about how to make a fast race car during the define stage of the process. Students shared their ideas and shared their points of view. Many students engaged in a debate over their answers and conferred on similar answers. A less successful structured collaborative activity occurred when the instructor encouraged students to share their final sketch design ideas at the conclusion of the ideate phase. Student participation was limited, and feedback provided between students was superficial. This outcome suggests that creating an environment for spontaneous collaboration might be more productive than structured activities, in some cases. Overall, the collaborative experience of the students aligned with research that supports the positive collaborative experiences and opportunities when using design thinking (Lugmayr et al, 2014).

The instructor invited students to engage in data analysis throughout the project. During the testing stage, students examined the drag coefficient and weight of their prototypes. From this data, students compared their data to the initial foam block. Mr. Thomas encouraged students to think about their data and how they might make changes to their prototype to improve their performance numbers. The analysis of data followed an iterative pattern allowing for multiple opportunities to engage. As students made changes to their prototypes, they followed the initial process of measurement to gain additional data. This collection of data and analysis created a cyclical cycle. Additionally, students were able to view and consider data created by other students in comparison to their car. I observed students fully engaging in this process and considering intensely the data received after each trial in order to make appropriate changes to their car.

Scholars suggest that design thinking has proven to be well suited to address the needs of students and industry to develop the skills necessary to successfully engage in the Fourth Industrial Revolution (Davis & Littlejohn, 2017; Koh et al., 2015). This study provided evidence of the ability of a seventh-grade teacher to create ample opportunities for students to practice these specific skills using design thinking. The use of design thinking, as evidenced in this study, provides a framework for and instructional opportunities to have students think critically, collaborate, and engage in data analysis, which are essential skills students must practice and develop. This study provides a model for how one might use design thinking to encourage the practice and retention of these essential skills.

Transferability of Design-Thinking Skills

Although this study provides evidence of student opportunities to engage and practice essential future-ready skills, one must consider the likelihood that these skills will be transferable. When interviewed about the use of design thinking during the study, students did not respond confidently to identify or consistently connect the steps to the process. Students demonstrated a simplistic understanding of design thinking and noted it was merely used in this project to solve a problem. However, to discuss the specific tenets of design thinking in the project, students required scaffolded assistance from the researcher. Notably, one student indicated that the design-thinking process was confusing.

This sense of confusion and inability to connect the design-thinking process to the project suggests that the skills practiced and learned from this study may not be easily transferred to other complex problems students will be asked to solve. Students

demonstrated the ability to complete the tasks given, which represented the stages of design thinking. However, verbal verification by students of the connection to design thinking and how this process was a key and central aspect of instruction or creating a fast race car was absolutely absent. This lack of confirmation may have been due to the lack of consistent instruction and connection of design thinking to the activities by the instructor. The teacher discussed design thinking as a series of actions early in the project and the steps of design thinking were present in the packet where students recorded their data. However, the teacher did not dedicate consistent class time to explicitly connecting each step to the design-thinking process.

The dearth of dedicated class time provided to explicit instruction on the design-thinking stages allowed students to spend more time engaged in learning activities, which promoted the practices associated with the design-thinking stages. This format may have allowed students to gain a deeper understanding of the skills correlated with each stage. Additionally, students may have been able to focus more intently and critically on their project. As a result, it was possible that students gained a deeper understanding and had a more meaningful experience during the design-thinking project. However, students engaged in the design-thinking process without fully understanding how each activity connected to the purpose of each stage. This lack of clear connection may lead to a lack of transfer of skills. This possible lack of skill transfer is a missed opportunity and has the strong likelihood of limiting the impact these skills could have on future-ready preparedness and the ability to successfully engage in similar projects.

Implications for Middle-Level Teaching and Learning

Researchers showed that middle school instruction often comprises fact-based didactic instruction that fails to stimulate students to think critically, collaborate, or develop the higher order skills mentioned previously (Brooks, 2014; Eccles & Roeser, 2011; Larson, 2000). The desire of middle school students to be active learners and decision makers in their environment is well established (Brooks, 2014; Eccles & Roeser, 2011). Design-thinking instruction is a possible solution to the mismatch of the middle school classroom environment and the needs and desires of middle school learners. This study provides evidence of one middle school classroom that involved an active-learning environment where students were able to think critically, collaborate with their peers, and demonstrate agency and decisions during the learning process, while practicing the development of higher order skills.

I observed and reported on students creating and making personalized decisions in their project. Collaboration among peers was well established using directed and self-guided opportunities. Further, the instructor gave the students a complex problem through which they were able to create a tangible solution among many open-ended solutions. Additionally, students were encouraged to experience and confront failure. The learning process from failure allows for the creation of an optimal design (Benson and Dresdow, 2015). The ability to fail and learn from that failure is not a commonly accepted practice within most middle school classrooms. This is true for both teachers and students. The enactment of design thinking in this classroom created an environment that represents several characteristics of optimal middle-level learning. This study provides a model for educators on how to structure and create activities that provide the level of engagement

and motivation needed for middle school learners. Consequently, design thinking shows abundant promise as an innovative and excellent way for students to learn, particularly those in middle school. Design thinking represents an instructional method that allows teachers to push back against the norms of dominant and teacher-centered instruction readily present in U.S. middle schools.

Although the study evidence strongly supports the suitability of design thinking for middle-level learners, several factors may have influenced these assumptions. First, I completed the study in a classroom focused on technology education. In this content area, projects tend to be more hands-on and interactive than in a traditional classroom. Second, the activity of creating a CO_2 race car lends itself to high motivation, high interest, and open solutions. Last, the enthusiasm and expertise of the teacher providing this instruction may have created an outside-the-norm experience of the use of design thinking. Even given these predetermined factors, the instructor's implementation of design thinking helped build an appropriate pedagogical environment for middle school students.

Connections to Constructionism

The theoretical construct of constructionism serves as the foundation for design thinking. The social construction of knowledge, in addition to the mental construction of a real-world object, is fundamental to learning (Papert, 1993b). Simply stated, learning occurs when people use their own hands to create a tangible object (Dowling, 2012). The hands on process enhances understanding of content, engagement, and long term retention. Students who participated in this study strongly endorsed the positive influence of creating a tangible object with their hands. Observational evidence revealed that

students were learning and discussing desired outcomes while creating the prototypes and final car designs. Further, the prototypes and testing required students to engage socially with their teacher and peers to understand the concepts presented in the lesson. Students also endorsed the connection between learning and using their hands to create. Students noted that when they were using their hands, they were better able to understand the process and standards being taught. Additionally, they enjoyed working with their hands and stated that this increase their motivation.

Constructionism requires facilitation, intellectual support, and appropriate materials from an instructor (Papert, 1993b). The instructor provided the students in this study a high level of individual and full-group facilitation while engaging in the project. The instructor provided verbal encouragement, examples of finished products, and visual examples for students as they worked on their designs. The teacher also offered students small-group instruction on sketching. Further, the instructor provided the appropriate materials and tools to create the physical prototypes necessary for the project. The facilitation, support, and physical materials provided for students supported the opportunity for student success and engagement in an authentic constructionist classroom environment. The results of this study provide a practical example of constructionism in action in a K–12 classroom. Evidence of students' increased engagement and understanding of concepts supports the benefits of creating a constructionist classroom.

Future Research

This study revealed topics surrounding the implementation of design thinking that warrant further investigation. One goal of this study was to add to the scholarship of how design thinking could be in implemented in a K–12 classroom. Although this study

provided a detailed examination of one teacher's seventh-grade classroom, this is one case-study example in a unique setting and grade level, with unique content. To continue to develop a diverse compilation of scholarship on design thinking in the K–12 setting, further case studies should be completed. Case studies should target various K–12 grade levels, especially in middle and elementary grades; current research has focused mainly on high school and college classrooms and students. An increase in middle and elementary case studies would provide scholarship needed for educators to review and inform their practice. Additional studies should seek to illuminate ways practitioners navigate barriers to design thinking in various curricular and school contexts.

Scholarship should also be completed in classrooms with varying subject and content areas. This study was conducted in a technology-education classroom. Classrooms in this curricular framework possess a framework that invites and encourages the use of design thinking. Future research should be conducted in core-content classrooms, such as mathematics or language arts, to investigate the suitability and possible benefits of using design thinking in these subject areas. Researchers should continue to focus on the ability of instructors to connect core-content standards to design-thinking projects. Although this study did offer some evidence of success in this area, the apprehension and reluctance of teachers to use design thinking instructional strategies to teach core content remains. The development of scholarship and possible positive potential for students when engaging and learning core content will be essential for teachers to employ design thinking. Increasing the diversity of studies examining various types and methods of projects to engage students in the design-thinking process will provide further support.

The study conveyed here focused on student acquisition of skills necessary to engage successfully in the Fourth Industrial Revolution. The data suggested that students received ample authentic opportunities to engage in activities that may have developed these specific skills. However, this study did not render data to support the concept that students will transfer these skills when working in other settings. The transfer of these future-ready skills is essential, and an essential goal of using design thinking in the classroom. Researchers should develop scholarship examining the transferability and practice of future-ready skills by students who have been participants in design-thinking classrooms. The ability of students to internalize and then enact these skills in the future is essential for their success.

Finally, researchers should study the implications of professional development on the successful integration of design thinking in a K–12 classroom. Although this study did not focus on collecting or examining data related to this topic, the possible influence of substantial professional development came through in the findings of this study. As with many teaching strategies, proper professional development is essential for success. Design thinking is an innovative and complex process that requires the instructor to consider many factors to deliver accurately. Additionally, the paradigm shift required by teachers to engage in instruction that allows for significant student agency and choice will be significant. Administrators will need to be prepared for possible resistance from teachers and prepare to provide adequate professional development. In this case study, the strategic direction of the school centered on design-thinking instruction. The context and strategic vision administrators will need to provide for teachers embarking on design-thinking instruction will also need to be firmly established. Future researchers should

comprehensively review how administrators might provide professional development to teachers to successfully employ design thinking in their classrooms.

Summary

The Fourth Industrial Revolution has begun and requires the businesses of today to reevaluate the skills their employees possess. At the same time, complex social problems require that future-ready citizens have the ability to collaborate and think critically to generate viable solutions. As a result of these shifts, educators are encouraged to consider how they might restructure their classrooms and engage students in necessary skill development. Design thinking is promulgated as a possible innovative solution to assist educators in exposing their students to the future-ready skills necessary to be successful citizens and employees.

This scholarship examined a seventh-grade classroom and one teachers' effort to create an innovative learning environment centered on the use of design thinking. In the study, I investigated the presence or absence of the stages of design thinking in classroom instruction. The research also entailed exploring the data for possible benefits or limitation of design-thinking instruction.

The results of the study provided a comprehensive example of how instructors can implement design thinking in a classroom. This inquiry documented the authentic engagement of students involved in activities that promoted the experience of design thinking. The examination of the presence of stages of design thinking produced varied results. Although most stages were well represented, the stage of empathize was noticeably underrepresented in the data. The data also indicated possible benefits of students learning skills such as critical thinking, collaboration, complex problem solving,

and data analysis. The constraint of instructional time provided some possible limitations for implementation. The study also revealed the benefits of hands-on learning and the possible ability to transform middle-level educational-classroom instructional practices. I recommend further empirical studies in various settings and content areas. Additionally, scholarship on the transferability of skills learned during design-thinking instruction to other settings should be examined.

Schools must begin to examine ways to meet the needs of students and the future world they will enter. As a result of this study, educators have an authentic and expansive example of how design thinking may be a possible solution to a growing need. This study built on prior research and provides further evidence of the use of design thinking to engage students in meaningful learning, providing hands-on opportunities to learn collaboration, critical thinking, and complex problem solving skills that are essential to future employment and civic engagement. Although design thinking is not the only manner in which these skills can be learned, the possibility and innovative effect they have on classrooms and students require the attention of educators as they continue to pursue innovation in schools.

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Appendix A

Teacher Informed Consent Form

You have been asked to participate in a study conducted by student researcher, Matthew Campbell. This study partially fulfills the requirements for Matthew Campbell's Millersville University Education Leadership Doctoral Program. Please read the following carefully and ask any questions that you have before signing. Signing your name and the date at the bottom indicates that you understand the information provided below and agree to participate.

Project Title

Design Thinking in a 7th Grade Classroom: A Case Study

Involvement

My name is Matthew Campbell, and I am a doctoral student at Millersville University in the Education Leadership Program. I also serve as the Director of Learning Technologies at the Milton Hershey School.

Overview

The purpose of this study is to better understand the use of design thinking in a 7th grade technology education classroom. If you agree to participate in this study you will be asked to do the following:

1. Participate in no more than four audio-recorded interviews (each lasting no more than one hour) at the beginning, middle, and end (within two weeks of completion) of the race car design unit.
2. Allow the researcher to observe all scheduled class meetings of your first period technology education class throughout the race car design unit. The instructional periods will be audio recorded and the researcher will take field notes.
3. Provide me with copies of any instructional materials you used to teach the unit on race car project using design thinking.

Risk & Benefits

Because of the nature of the data to be collected in this study, it may be possible to deduce your identity; however, the findings of this study will be reported in a way that will not identify you. The results of this study will be shared with you for review and application as you see fit. Additionally, it will potentially inform the professional community about how teachers might best use design thinking in a technology education classroom.

Compensation

There is no compensation for participation in this study.

Confidentiality

The information that you provide for this study will be handled with confidentially. All identifying information will be removed from all data collected and replaced with pseudonyms. Audio recordings of interviews, classroom observations, field notes, and any other collected data will be kept for three years in compliance with federal law. After three years from the end of this study, all of the data mentioned above will be destroyed.

Voluntary participation:

Your participation in the study is completely voluntary. Your end of year evaluation and job performance will in no way be connected or associated with your participation in this study.

Right to withdraw from the study:

You have the right to withdraw from this study at any time without penalty. Your end of year evaluation and job performance will in no way be connected or associated if you decide to withdraw from this study. If you have participated in an interview, the audio recording of that interview will be destroyed should you withdraw from the study.

How to withdraw from the study:

If you want to withdraw your student from the study, please contact Matthew Campbell. There is no penalty for withdrawing.

For more information

Should you have any questions about this project at any time, please contact Matthew Campbell or Dr. Sarah Brooks. They will be happy to answer any questions and provide you with additional information.

Responsible Parties

This study has been approved by the Millersville University of Pennsylvania Institutional Review Board. Dr. Rene Munoz, Director of Sponsored Projects and Research Administration can be contacted with any questions at either (717) 871-4457 or (717) 871-4146 or at rene.munoz@millersville.edu.

_____ _____

Participant Signature Date

Matthew Campbell
Student Researcher
Millersville University
Educational Leadership Doctoral Program
mscampbe@millersville.edu
717-520-2404

Dr. Sarah Brooks, Ph.D.
Dissertation Chair
Millersville University
College of Education
Sarah.Brooks@millersville.edu
717-871-4872

Appendix B

Parent/Sponsor Informed Consent Form

Your student has been asked to participate in a study conducted by student researcher Matthew Campbell. This study partially fulfills the requirements for Matthew Campbell's Millersville University Education Leadership Doctoral Program. Please read the following carefully and ask any question you have before signing. Signing your name and the date at the bottom indicates that you understand the information provided below and agree to allow your student to participate.

Project Title

Design Thinking in a 7th Grade Classroom: A Case Study

Involvement:

My name is Matthew Campbell, and I am a doctoral student at Millersville University in the Education Leadership Program. I also serve as the Director of Learning Technologies at the Milton Hershey School.

Overview:

The purpose of this study is to better understand the use of design thinking in a technology education classroom. If you agree to have your student participate in this study they will be asked to do the following:

1. Your student will be asked to sign a minor/student assent form outlining their requirements, confidentiality, right to withdraw, and other information similar to the information in this consent form. A copy of the minor/student assent form will be provided to you for your review.
2. Students who participate in this study will attend their regularly assigned technology education classes. Copies of the some of the work your student completes may be collected for analysis as part of the study. Your student's name will be removed from all collected work.
3. Students who volunteer will be interviewed (as many as two times) by the researcher about the technology education class and the project they are going to be completing. These interviews will take place at your student's convenience, before or after school, and will last no longer than 30 minutes. The interviews will be audio-recorded and later transcribed. During an interview, your child can skip any questions that make him/her uncomfortable, and he/she can stop the interview at any time. Your child will not miss any instructional time as a result of this study.

Time Required:

The study will require no more than 60 minutes of your child's time, beyond the time your student normally spends in class.

Risk & Benefits:

Because of the nature of the data to be collected in this study, it may be possible to deduce the identity of your student; however, the findings of this study will be reported in a way that will not identify your child. The results of this study will not benefit your student directly. The study may inform the professional community about how teachers might best use design thinking in the classroom.

Compensation:

There is no compensation for participation in this study.

Confidentiality:

The information that your student provides for this study will be handled with confidentially. Data collected from your student will be assigned a code number. The listing connecting your student's name to this code will be kept in a locked file. The list along with audio recordings of interviews, audio recordings of classroom instruction, notes, and any student artifacts will be kept for three years in compliance with federal law. After three years, all the data mentioned above will be destroyed. All identifying information will be removed from all data collected and replaced with pseudonyms.

Voluntary participation:

Your student's participation in the study is completely voluntary. Your student's grades will not be affected by their participation in this study.

Right to withdraw from the study:

You have the right to withdraw your student from the study at any time without penalty. Also, your student has the right to withdraw from the study at any time. Withdrawing from this study will not affect your student's grades. If your student has participated in an interview, the audio recording of that interview will be destroyed should he/she withdraw from the study. Copies of your student's work will also be destroyed.

How to withdraw from the study:

If you want to withdraw your student from the study, or if your student wants to withdraw him/herself, contact Matthew Campbell. There is no penalty for withdrawing.

For more information:

Should you or your student have any questions about this project at any time, please contact Matthew Campbell or Dr. Sarah Brooks. They will be happy to answer any questions and provide you with any additional information.

Responsible Parties

This study has been approved by the Millersville University of Pennsylvania Institutional Review Board. Dr. Rene Munoz, Director of Sponsored Projects and

Research Administration, can be contacted with any questions at either (717) 871-4457 or (717) 871-4146, or at rene.munoz@millersville.edu.

_____	_____
Parent/Sponsor Signature	Date
Matthew Campbell Student Researcher Millersville University Educational Leadership Doctoral Program mscampbe@millersville.edu 717-520-2404	Dr. Sarah Brooks, Ph.D. Dissertation Chair Millersville University College of Education Sarah.Brooks@millersville.edu 717-871-4872

Appendix C

Minor/Student Informed Assent Form

You have been asked to participate in a study that Mr. Campbell is doing. Please read this sheet and ask any questions you have before signing. Signing your name and the date at the bottom shows that you understand the information and you want to join the study.

I want to learn about ways students think and learn when working on hands-on projects in class. I am interested in how you work together in a group and how you come up with ideas to create a project. As part of this study you will be asked to:

1. Sign this form stating that you would like to join the study.
2. Attend class when possible and complete all classwork as assigned by the teacher.
3. Allow me watch your class as you complete your assignments.
4. Talk to Mr. Campbell after school (no more than 2 times) about your classwork in your exploratory technology education class. The appointments to talk with Mr. Campbell will be about 30 minutes long. Your talk with Mr. Campbell will be voice recorded using an iPad and later put into words on a computer. You can stop the interview at any time or choose not to answer any questions which makes you feel uncomfortable. You will not miss any class time for these talks with Mr. Campbell.

If you join this study, you may not want people to know who you are by looking at your work or hearing your answers given to Mr. Campbell. The classwork and answers you give during appointments to talk with Mr. Campbell will be kept private. Mr. Campbell will make sure that the classwork, answers, or any information about you give will not be able to be used by anyone to tell who you are. All the classwork and information will be locked up and password protected so only Mr. Campbell can see them. All data will be kept for three years and then thrown away.

You do not have to join this study. If you join this study and change your mind, you can stop at any time. You will not be in trouble and your grades will not change or be lowered if you do not join or quit this study.

If you think of questions you want to ask at any time about this study, please contact Mr. Matthew Campbell, Mr. Zak Marinkov - 7th Grade Technology Education Teacher, or Dr. Sarah Brooks. They will be happy to answer any questions and provide you any additional information.

_____ _____

Participant Signature Date

Matthew Campbell
Millersville University
717-520-2404

Student Researcher
mscampbe@millersville.edu

Appendix D

Teacher Interview Protocol

Beginning of Study Interview

1. What does the term "design thinking" mean to you?
2. Where and how did you first learn about design thinking?
3. In what ways have you been prepared as a teacher to deliver design thinking n your classroom?
4. What additional professional development have you received related to design thinking?
5. What do you see as the primary goal of using design thinking in a classroom?
6. How long have you been using a design thinking approach in your teaching?
7. Tell me how you decided on using design thinking for this unit?
8. What are your expected student outcomes when you integrate design thinking practices into your classroom lessons?
9. How did you prepare to teach this technology education unit using design thinking?

Middle of Study Interview Questions

(Further questions for this interview will be created from observations of classroom instruction)

10. What strategies did you using to infuse design thinking into the lessons?
11. What aspects of design thinking are best represented in this unit?
12. Tell me about the student activities planned for this lesson and how they promote a design thinking mindset.
13. Tell me about how your plan for assessment in this unit?

End of Study Interview Questions

(Further questions for this interview will be created from observations of classroom instruction)

14. What are some of the barriers or areas of weakness you have observed for this design thinking unit?
15. What are some of the benefits or areas of strength you anticipate for this lesson as it related to design thinking for this project?
16. Tell me about how the core science curriculum in connected to use of design thinking strategies?
17. How comfortable are you teaching design thinking?
18. What most surprised you about the students' ability to engage in the design thinking activities?
19. From your perspective what did the students learn about the content through the design thinking activities?
20. What is your overall opinion of the use of design thinking in the classroom?

Appendix E

Student Interview Protocol

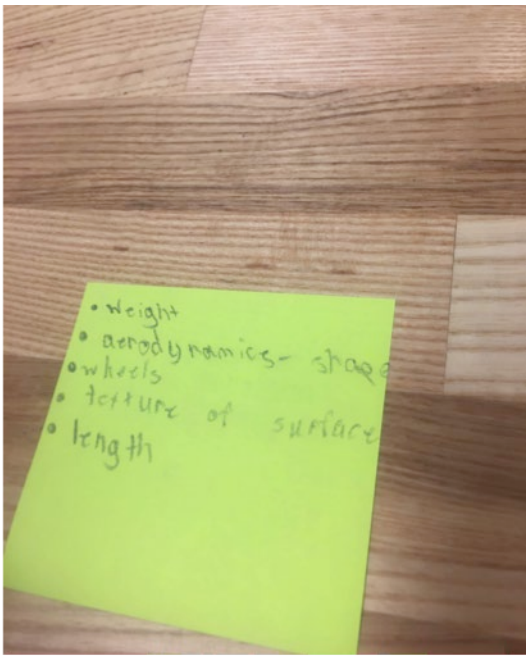
(Questions will be chosen from this protocol to be asked in the first or second interview based on classroom observations.)

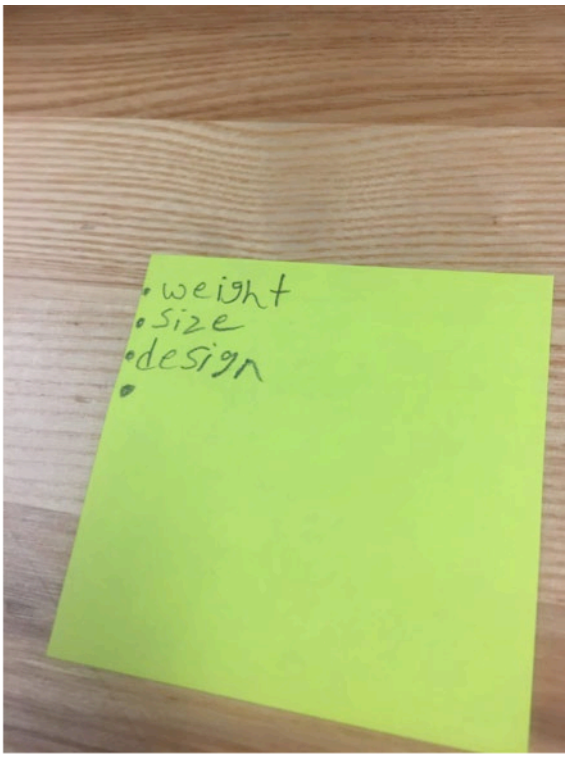
1. Tell me about what you are currently learning about in your technology education exploratory classroom.
2. How did you feel about working on race cars?
3. Tell me about your experience with working others in a group to complete this project?
4. What areas of the project were most easy to work with others?
5. What areas of the project were most challenging to work with others?
6. What benefits or concerns did you experience when working with others?
7. What kind of problem did the teacher ask you to solve?
8. What did you do first once you were given a problem to solve?
9. Tell me about how you created different models or prototypes for your car?
10. Tell me how you tested the model or prototype?
11. What did you do to get feedback on your prototype?
12. What did you do with the feedback?
13. What questions did you ask yourself or did you wonder about while working on the project in class?
14. Did your teacher talk to you about design thinking?
15. How would you describe design thinking?
16. What part of design thinking is most important?
17. What is the easiest part?

18. What is the most difficult?
19. Tell what you liked most about the project?
20. Tell me what you liked the least?
21. Tell me if there was any connection to content other than technology education that you learned or was taught during this unit?
22. What do you think you learned from this project?
23. What would you think if teachers used design thinking in more of their classroom assignments?

Appendix F

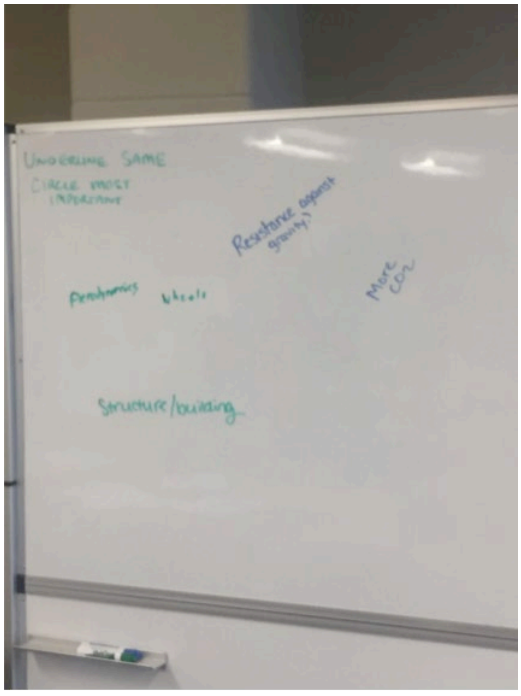
Post-IT Notes Activity

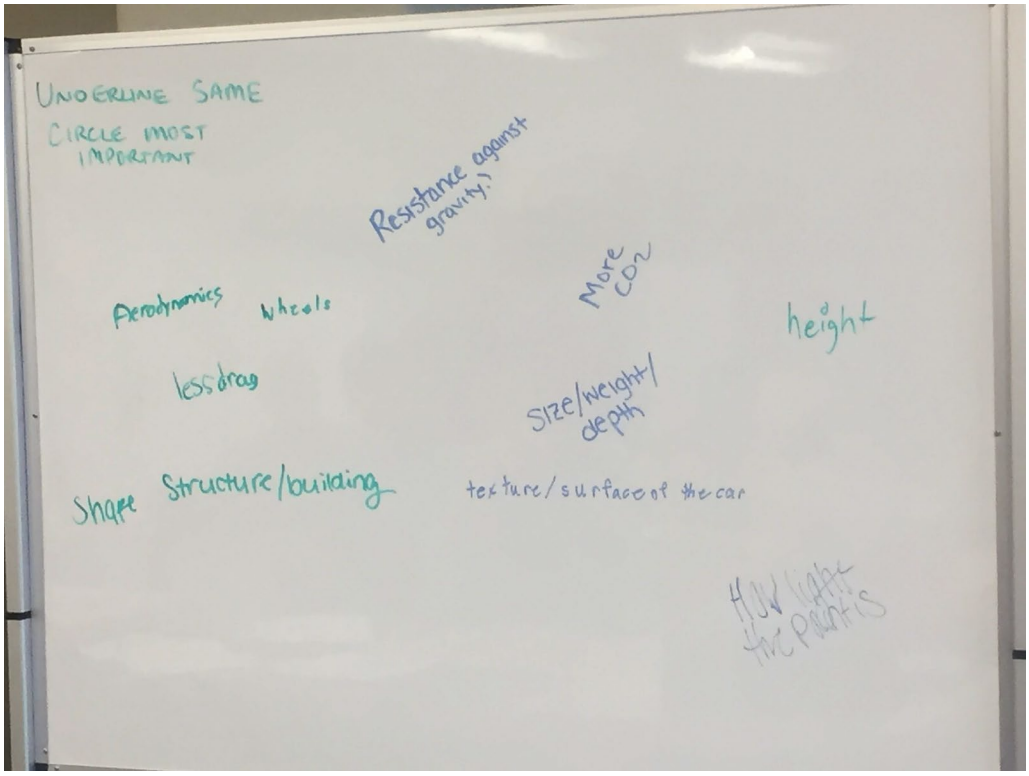




Appendix G

Student-Defined Criteria Board





Appendix H

Forces that Affect a CO_2 Car's Performance

Forces that effect a CO_2 Car's performance

- Everyone wants to design a car that will scream down the track and leave his or her classmates in the dust, right? Well, designing a race car is like any other design challenge. In order to do well, you have to know what you're doing, and this requires some homework.
- Before you start whining "why can't he just tell me what to do," remember: It's your car. If you don't care about any of this, then you just won't do very well, giving your classmates the power to crush your car come race day. Can you say embarrassment, boys and girls?
- Making a super fast car involves learning about the principles behind race cars, the designing involved, and the constraints the project must follow. Read, learn, and crush the opposition!

Newton's Third Law:
"For every action, there is an equal and opposite reaction."

You see, it works like this: when the CO_2 race car is shot out of the starting gate, the air escapes with a great deal of force towards the rear of the car. And just as good Sir Isaac Newton would have predicted, the car reacts in the opposite direction with equal force rocketing down the track. Our CO_2 race car is pushed by the compressed AIR.

Designing is like a balancing act full of tradeoffs. When you do one thing to overcome a problem, often you create another totally different problem (hopefully, only one). Many times a solution is the midpoint between the two problems, never solving either entirely. It's a game of give and take. And in CO_2 race car design, it is no different. Designing a CO_2 car can be broken into five main principles.

Designing Principle No. 1: Weight/Mass

CO_2 race cars are a great deal lighter than barbells, but they still have weight; what scientifically we call Mass. This comes into play when students choose their body block from which to construct their cars. When doing so, they will be faced with blocks that weigh as little as 30 grams and ones that weigh upwards of 130 grams. Once again, it should be obvious that it takes less force to push 30 grams than it does to push 130. So why on earth would someone want to choose a 130 gram body block? It is important to remember that your car only races once. It doesn't matter if the car breaks during the race as long as it crosses the finish line, the will time count. (Assuming it meet all of the minimum size restrictions)

The Balancing Act:

Advantages:

Cars with less mass go much faster.

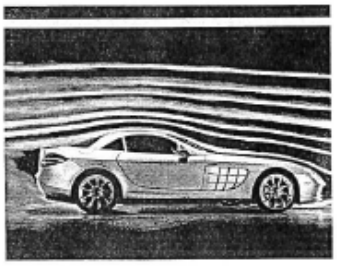
Disadvantages:

Cars with less mass are less stable and less durable. (Greater possibility of breaking during construction/racing.)

Designing Principle No. 2: Aerodynamic /Drag

Take a piece of balsa wood, slap wheels on it, shoot it down a track at 80 MPH and the air rushing over the body and wheels will try to slow it down. Scientifically this is called **drag: the resistance of wind moving over an object.**

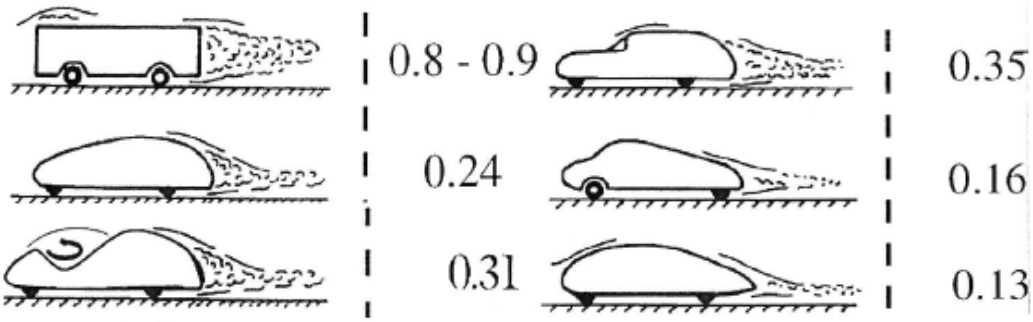
So how do you overcome drag? Start by making the body as aerodynamic "clean" as possible. Think of vehicles designed for high speed such as rockets and jet fighters and go from there. But don't forget the tires themselves have drag and friction. Think carefully when you choose your tires.



Turbulent Flow vs. Laminar Flow

Turbulent = Rough Laminar = Smooth

Numbers are equal to the car's Drag Coefficient (Lower the numbers area the better)



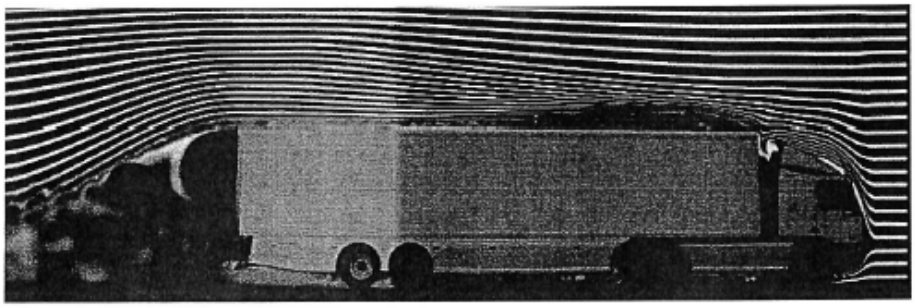
The Balancing Act:

Advantages:

Aerodynamically shaped cars have less drag so they go faster.

Disadvantages:

Aerodynamically "clean" cars are more difficult to build and may weigh more depending on shape chosen.



Designing Principle No. 3: Friction

Thanks to our friend gravity, everything has friction. On a CO_2 car, friction occurs primarily in three places: between the wheels and the ground, between the axles and the car body, and between the eye-hook and the fish line track. So how do you eliminate friction? You can't. You can only reduce friction.

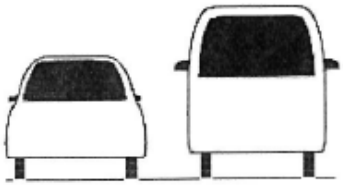
1. Make sure the tires are not rubbing on the car body.
2. Make sure the axles can freely spin inside the cars body.
3. Poorly aligned eye-hooks are often the cause of a slow car.

The Balancing Act:

Advantages: A friction filled car is easy to build. A friction filled car is slow, so it tends to be more durable.

Disadvantages: Reducing friction takes a lot of extra effort, time and patience.

Designing Principle No. 4: Frontal Area



Frontal Area describes how much area in sq feet a car has to punch a hole through the air. The larger the frontal area of car the more force required to move the car. Thus the slower the car will go with the same amount of force applied to it. With

everything else being equal a car with a smaller frontal area will beat a car with a larger frontal area.

Designing Principle No. 5: Design Constraints

In the real world most everything has limits. That limit could be technology available, labor available, materials, or cost. For example, oil tankers are designed to be just wide enough that they will fit through the Panama Canal. Our race cars also have a set of minimum and maximum dimensions, called constraints. One thing is sure: if your car doesn't meet the minimum size dimensions, it won't be racing in the competition and possibly not at all (if deemed unsafe). Without design constraints a competition would be unfair and unsafe.

The Balancing Act:

Advantages:

Cars that follow a design constraints can compete equally and safely.

Disadvantages:

Cars may go faster if a design constraints where not followed, but will be disqualified and could prove to be dangerous.

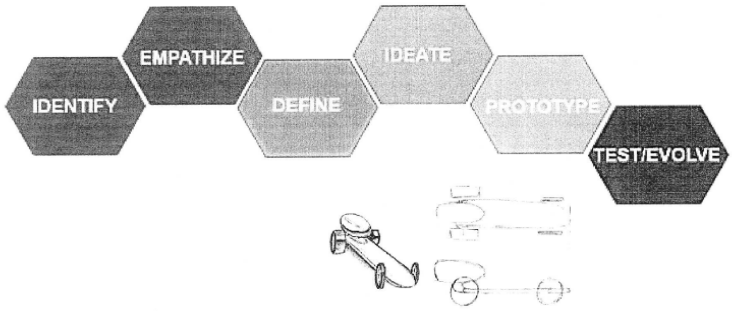
Appendix I

Design-Thinking Process Building CO_2 Dragsters Packet

The Design Thinking Process

Building CO2 Dragsters

GRADE
Thumbnail Sketches_____/10
Foam Prototype_____/20



Engineering and Design	Project Title- CO2 Car Design Brief
Name:	Date:

The Design Brief

The Design Brief Should:
1. Describe what the designer (you) will do.
2. The design brief will act as an outline to keep the designer on task.

Identify The Problem

Identify The Problem:
1. Problem,Challenge, or Goal

1._____

_____

_____

Engineering and Design	Project Title _____
Name:	Date

Specifications
The specifications should **clarify**, **Set limits**, and **help direct the designer efforts.** Develop criteria and constraints.

Specifications

1. Write down at least **5** specifications, feel free to add more as you come across them.

1. _____ 6. _____
2. _____ 7. _____
3. _____ 8. _____
4. _____ 9. _____
5. _____ 10. _____

Engineering and Design	Project Title _____
Name:	Date

Developing Solutions:
You need to come up with many possible solutions (thumbnail/sketches).

Ideate

	Student	Teacher
Top View	____ 10	____ 10

Side View	Example
Example	

Engineering and Design	Project Title _____
Name:	Date

Developing Solutions:
You need to come up with many possible solutions (thumbnail/sketches).

Ideate

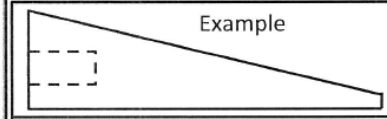
IDEATE

Student	Teacher
___/10	___/10

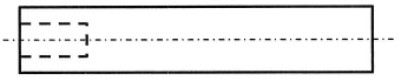
Top View

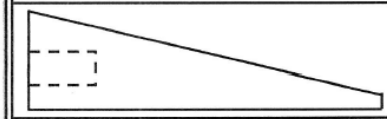
Side View

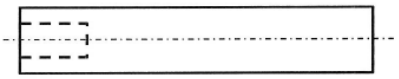
Example

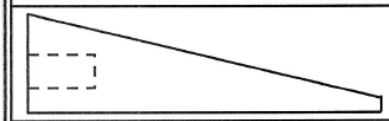


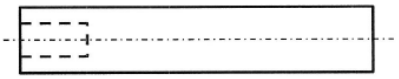
Example

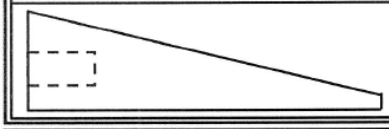


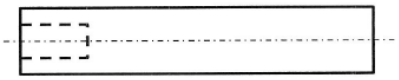












Engineering and Design

Project Title _____

Name:

Date

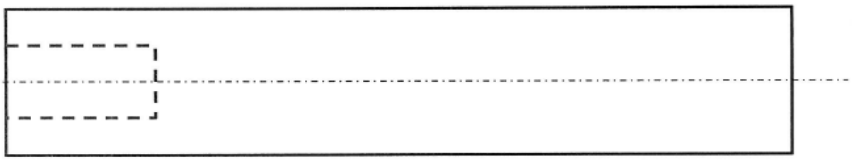
Developing Solutions:
You need to come up with many possible solutions (thumbnail/sketches).

Ideate

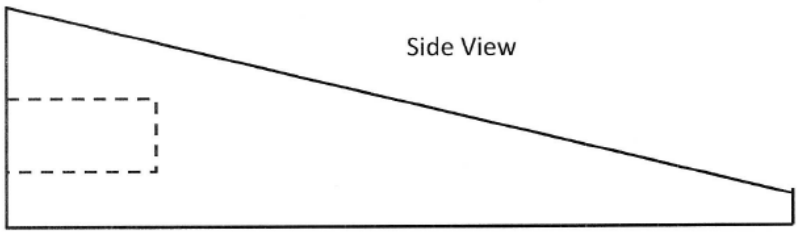
IDEATE

1. Sketch a larger version of the car or combination of the cars you like the best.

Top View



Side View



Engineering and Design

Project Title _____

Name:

Date

Choose your best developed solution or a combination of them and build a model/**prototype**

Model /Prototype

(This Prototype will be made out of Styrofoam)

Model:
A physical representation of something usually made to a smaller scale. Models are made out of a material that is easy to work with. (cardboard, Styrofoam, clay).

Prototype:
A Prototype can be thought of as a working model. Example: a paper airplane could be a prototype of a glider.

List benefits of prototyping

1. _____
2. _____
3. _____
4. _____
5. _____

Engineering and Design

Name:

Project Title _____

Date

Build Best Solution
After redesigning your model/prototype, you will build your best solution out of the actual material balsa wood).

Build Best Solution

(This Car will be made out of Balsa Wood)

This will be done on a separate, 11 x 17 sheet of paper.

Engineering and Design

Name:

Project Title _____

Date

AERODYNAMIC DRAG

Test:
Explain how you tested your solution.

Test & Evaluate Solution

Evaluate:
Rating the different characteristics of your design.

Testing

1. How much was the foam blocks drag for aerodynamics? _____
2. What was your foam car's(prototype)**INITIAL** drag coefficient?_____

Evaluation

1. How did your design account for aerodynamics?: Explain_____

_____

Redesign

1. Did your redesign improve your car? Explain _____

_____

Evaluation

2. How do you "know" if it improved or hindered (hurt) your car?_____

_____

3. What is your car's **FINAL** drag coefficient? _____

Engineering and Design	Project Title _____
Name:	Date

WEIGHT

Test:
Explain how you tested your solution.

Test & Evaluate Solution

Evaluate:
Rating the different characteristics of your design

Testing

1. What was the **INITIAL** foam block's weight? _____
2. What is your foam car's (prototype) **INITIAL** weight? _____

Evaluation

1. How did your design attempt to account for weight?: Explain _____

_____

Redesign

1. Did your redesign improve your car's weight? Explain _____

_____

Evaluation

1. How do you know if it improved or hindered characteristic your car?_____

_____

2. What is your car's **FINAL** weight? _____

Engineering and Design	Project Title _____
Name:	Date

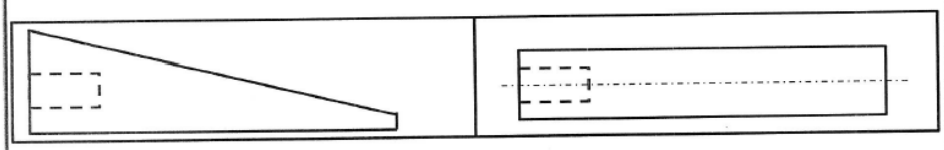
Redesign:
Redesigning is when you change your original design in the hope of improving on that design.

Redesign Solution

For your foam $C0_2$ car (prototype) I want you to:

TEST/EVOLVE

1. Draw your **original** cO2 car before you modified the car. On the same drawing shade in the area that you changed.
2. On the foam car please shade in the modified area.



3. Explain why you modified that part of the car? What were you trying to accomplish?

_____

_____

_____

Engineering and Design	Project Title _____
Name:	Date

Final questions/wrap-up

How did your final product turn out?

What would you change about the final design?

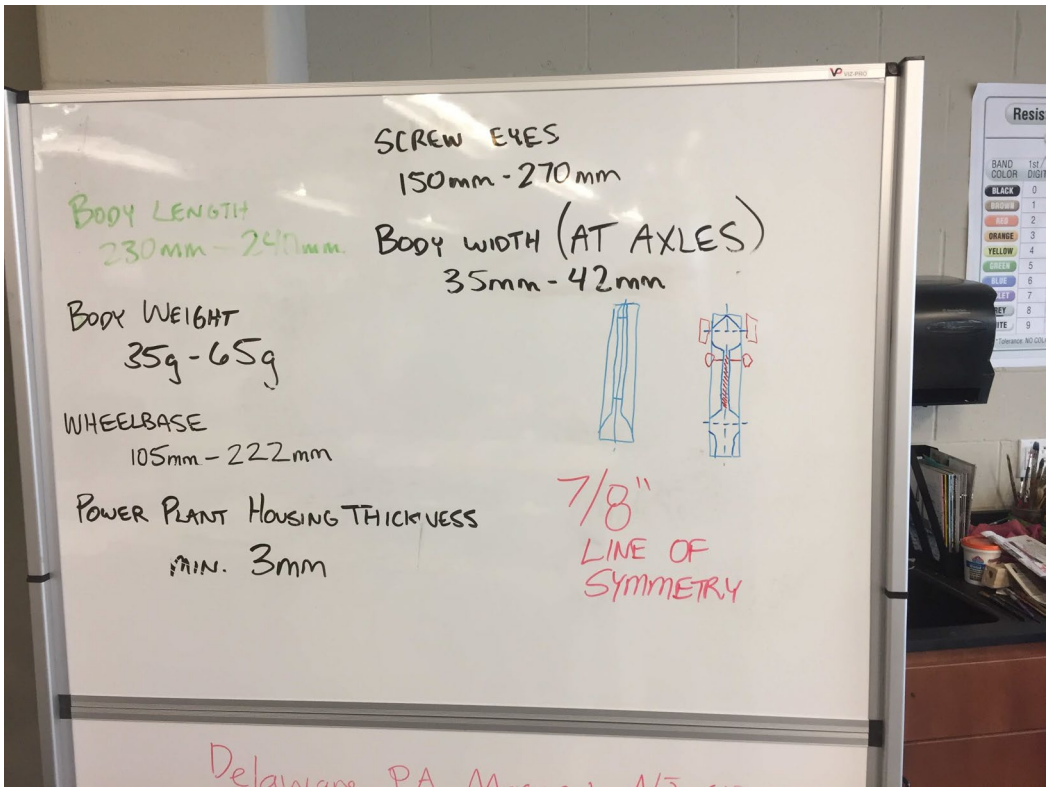
Was your car successful in solving the problem?

What would you change about this project? What did you like/dislike about the car project?

Engineering and Design	Project Title _____
Name:	Date

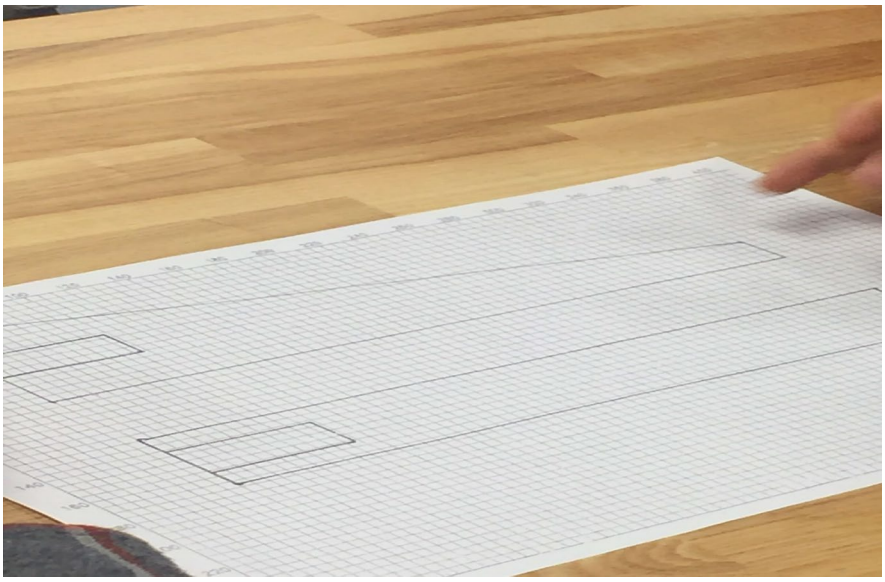
Appendix J

Teacher Defined Criteria Board



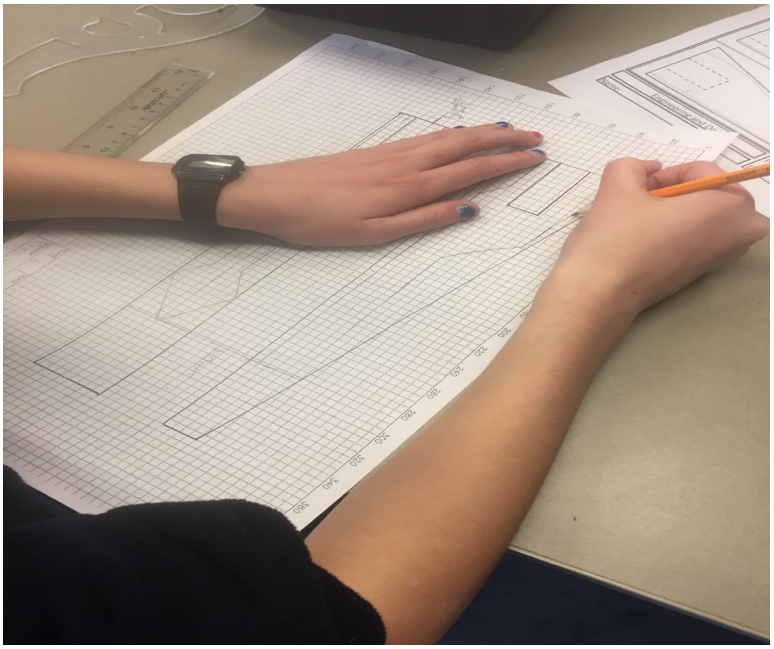
Appendix K

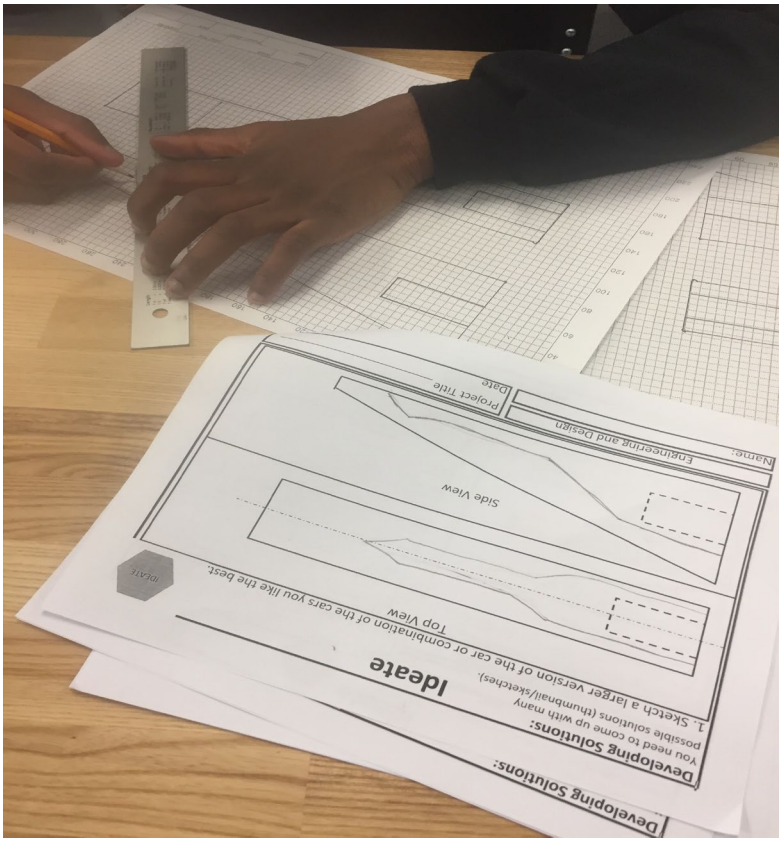
Teacher Sketch Demonstration



Appendix L

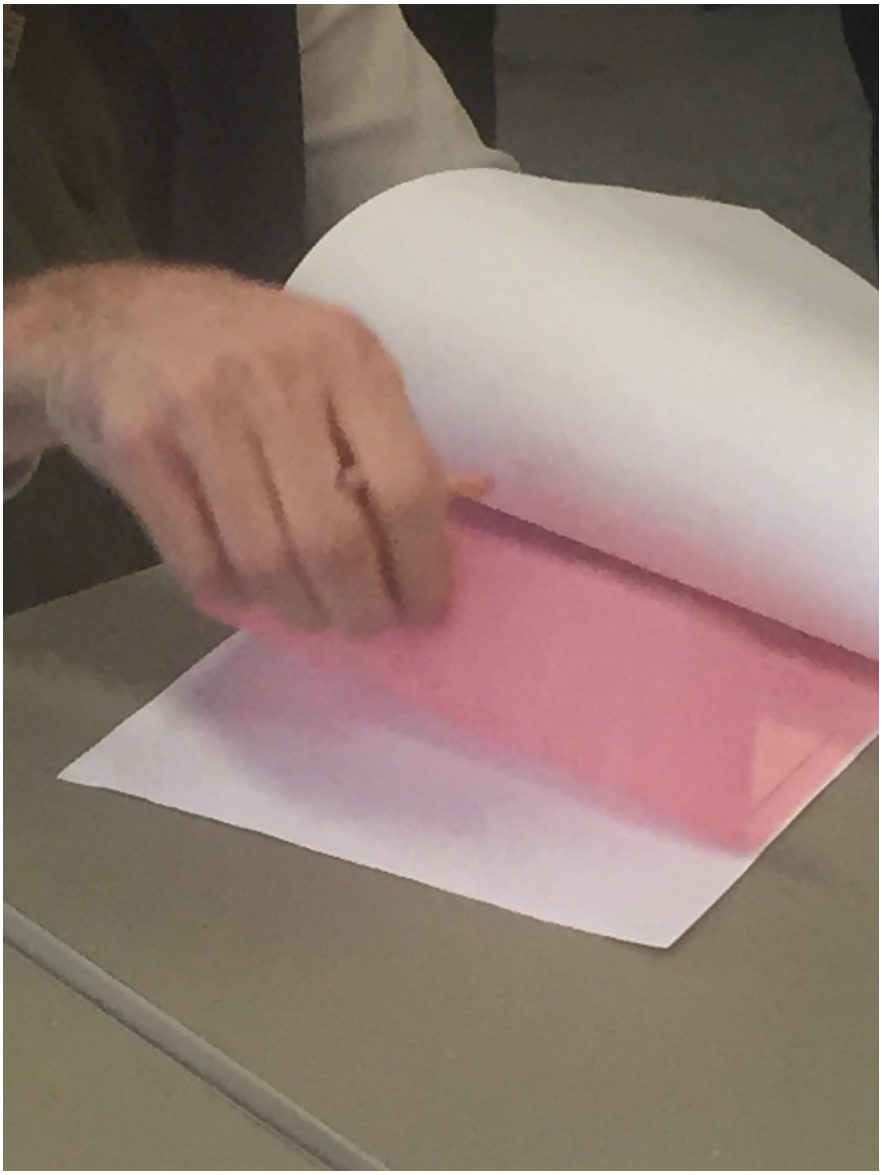
Student Sketching





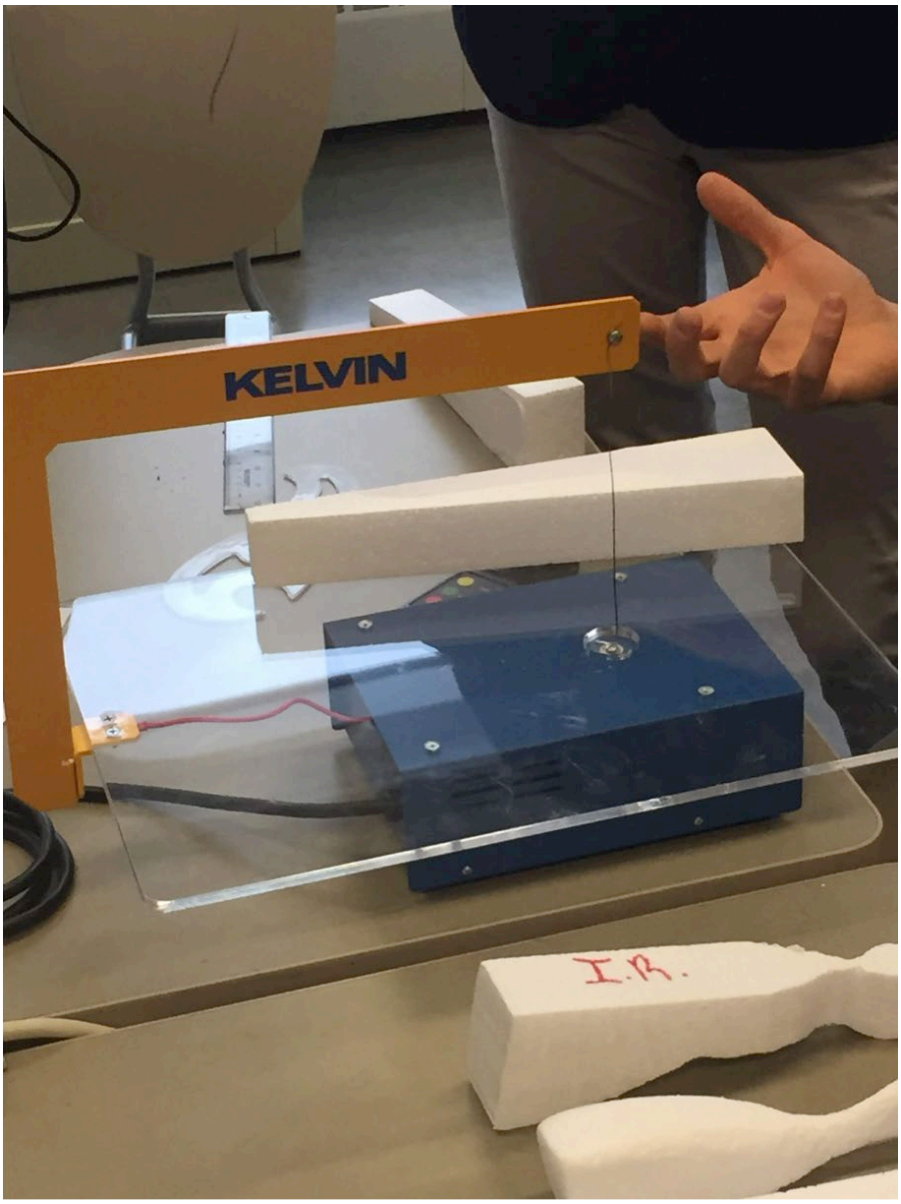
Appendix M

Sketch Transfer



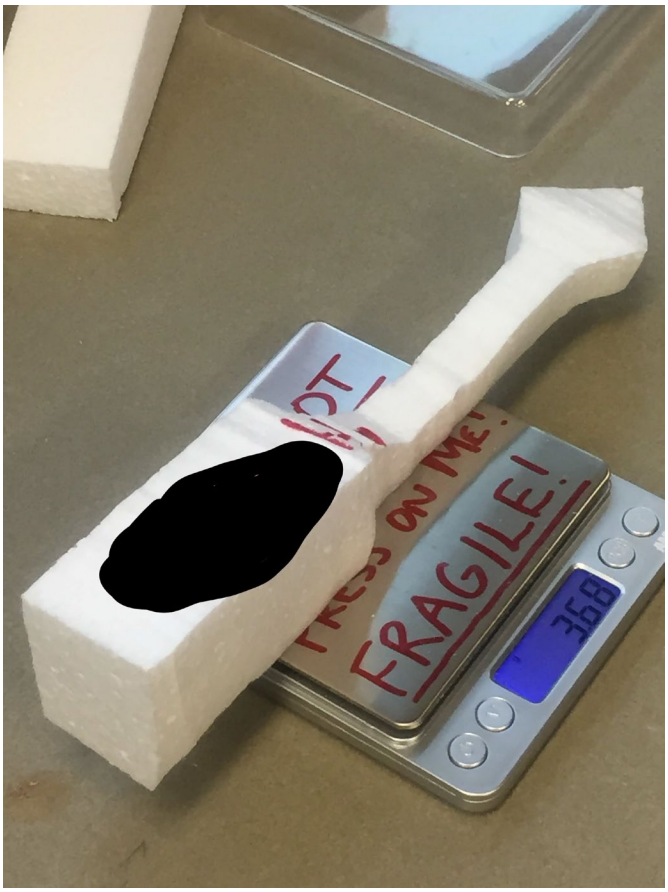
Appendix N

Foam Cutter Picture



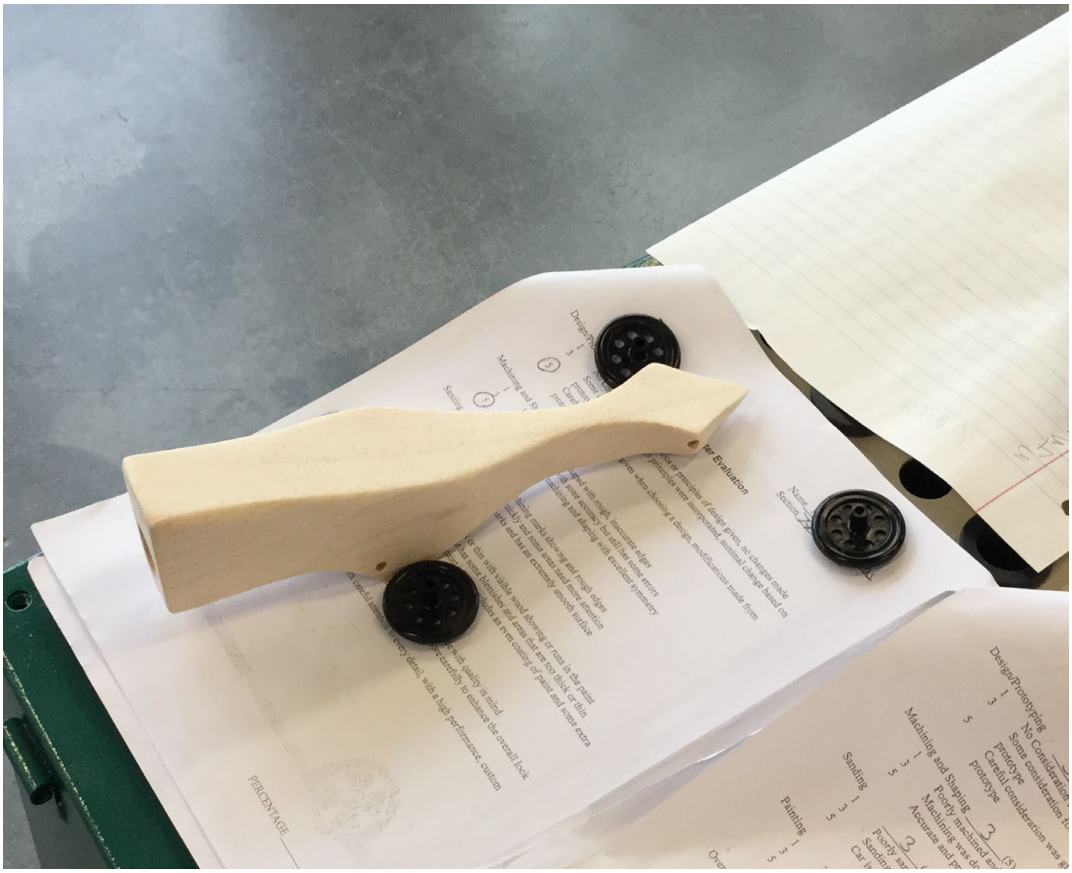
Appendix O

Wind Tunnel and Scale Pictures



Appendix P

Wooden Cut Car



Appendix Q

Painted Cars

Appendix R

Example of Final Car

Appendix S

Race Track