INCORPORATING ENGINEERING DESIGN IN THE TECHNOLOGY EDUCATION CLASSROOM THROUGH ACTION RESEARCH

by

KRISTOPHER BRENT HOLLERS

(Under the Direction of Jay Rojewski)

ABSTRACT

In recent years there has been a substantial push for the integration of the engineering design process in technology education classrooms. This drive towards cross-curricular incorporation of science, technology, engineering, and mathematics is often referred to as STEM. Its inclusion in courses is designed not only to enhance the study of the STEM subjects, but also to help develop problem-solving skills. While a number of standards have been developed by technology education professional organizations to further drive the movement toward engineering design, there is a noted lack of curricular resources and instructional methods for such integration. Therefore, this study employed an action research method to improve my instructional practice through the implementation and revision of engineering design curriculum across multiple high school robotics classes. Through the study, I saw improvements in my instruction specifically in the areas of resources developed, organization, timing, and knowledge. Additionally, students understood and applied the use of engineering notebooks, the engineering design process, and ballistics to solve an engineering design challenge.

INDEX WORDS: Engineering design, Action research, Technology education, Optimization, Design analysis, STEM, Secondary education, Robotics

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by

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DEDICATION

This dissertation is dedicated to my wife, for her kindness and devotion, and for her endless support during this process and to my parents for their unwavering dedication and hours of proofreading which helped me complete this momentous honor.

Who can find a virtuous woman? For her price is far above rubies (Proverbs 31:10)

Hear, my son, your father's instruction, and forsake not your mother's teaching, for they are a graceful garland for your head and pendants for your neck. (Proverbs 1:8-9, ESV)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 INTRODUCTION

Google, Apple, Tesla, and Microsoft. These names have garnered global recognition not only as successful businesses but also through the level of personal innovation that caused their meteoric rise to prominence. Daniel Pink, in his book *Drive* (2011), described the economy in which such companies thrive as a knowledge economy, or an economy in which the primary mode of innovation, creation, and profit is ideas. This concept is not new. Peter Drucker (1992) explained in *Managing the Future* that the importance of innovation and creative thinking by individuals in a knowledge economy is essential. While this is true for entrepreneurs like Sergey Brin and Elon Musk, it is also true of employees in both small and large organizations. Pink (2011) explained that for individuals to advance at work and be successful, they will need to solve problems. While the importance of problem-solving skills is apparent, the question becomes how to teach these skills to students so they are prepared for this new and challenging economy.

The National Academy of Engineering (n.d.) described engineers as creative problem-solvers who must design elegant solutions all that meet specific requirements. Therefore, teaching the process used by engineers to solve problems, known as the engineering design process, can aid students in developing their own problem-solving skills (Katehi, Pearson, & Feder, 2009). This realization combined with a concern that engineering, math, and science are not being taught effectively (Wormley 2003) has led to the emergence of the concept of STEM education (Brown, Brown, Reardon & Merrill, 2011). STEM, which stands for Science, Technology, Engineering, and Math, is an acronym that has garnered a great deal of interest and support from the educational community because of its integrated approach to teaching problem-solving skills (Kelley, 2010c).

Embracing the T in STEM education, technology educators have begun to incorporate engineering into their curriculum (Kelley, 2010c). The process of teaching engineering to students begins with the engineering design process (Asunda & Hill, 2007). This process is “a series of steps that engineering teams use to guide them as they solve problems. The design process is cyclical, meaning that engineers repeat the steps as many times as needed, making improvements along the way” (Teach Engineering, n.d.). There are a variety of models which teach this process with varying characteristics and steps (Smith, 2006). Kelley, Brenner, and Pieper (2010) examined two of the major engineering initiatives and found they lacked a clearly defined engineering design process and excluded a means for using math and science to improve student problem solutions. Rather, “tinkering” (p. 8) without any specific direction was a common practice of students to correct design flaws. The process of using math and science to generate improved solutions is known as optimization and analysis (Kelley, 2010b). Wicklein, Smith and Kim (2009) also concluded that these steps were not only missing from STEM curriculum, but are critical in the engineering design process.

Statement of Purpose

The National Center for Engineering and Technology Education (NCETE) was founded as a part of the National Science Foundation in 2003 to address the integration of engineering and STEM (Science, Technology, Engineering, and Math) based concepts into education (Hailey, Erekson, Becker, & Thomas, 2005). As a part of their mission, the NCETE set the goal of introducing the engineering design process into technology classrooms since many technology teachers are now being pushed to incorporate STEM principles in their curriculum.

Hailey et al. (2005) asserted that there is a distinct difference between the engineering design process and what the International Technology Educators Association (ITEA) set as standards for design. While technology educators have a design process as delineated by standard nine of the ITEA's *Standards for Technology Literacy* (2007) that is similar to the engineering design process, it lacks the steps of analysis and optimization. Using these scientific and mathematic principles, engineers determine the best (or optimum) solution and eliminate inferior solutions. This process generates a more robust design than the concept of trial and error which is advocated by the ITEA standard. The focus of this study is on the engineering design process and specifically analysis and optimization as its absence has been observed by Wicklein et al. (2009) in their research as well as in my own classroom practice. As such, the purpose of this action research study was to enhance my practice through the development of a unit of instruction that teaches high school students application of the engineering design process through integration of STEM concepts.

Research Questions

Throughout the course of research, my students completed a unit of content that involved a challenge requiring the use of the engineering design process and the mathematic and scientific concepts taught. Through each research cycle my instruction improved based on data collected and my reflection as an instructor-researcher. The overarching question that was answered at the completion of the research was:

> In what ways can I improve my practice of teaching the engineering design process through the application of action research methodology?

To better understand the specific components in the improvement of my practice and to ascertain a clearer understanding of the answer to this primary question, a set of questions were answered at the end of each research cycle:

1. To what degree do students understand the elements of the engineering design process, ballistic trajectories, and the laws of conservation of energy?
2. How effective were instructional strategies in enhancing student understanding of relevant mathematical and scientific concepts?
3. How do students explain the practical application of the content learned to their lives?

Conceptual Framework

While research is often used to develop educational theories, including practices, instructional design, and other aspects; a disconnect can exist between theory and practice (Mertler, 2014). Social science inquiry can lead to the development of ideas in a highly theoretical environment that are then passed down to teachers to implement into their instruction (Parsons & Brown, 2002). However, teachers often find difficulty in adapting such theory to the unique, localized classroom experiences. This gap has led to a surge in the application of action research as a methodological and conceptual underpinning for classroom research (Noffke & Somekh, 2009). Mertler (2014) described this focus on action research as the desire to connect theory and practice in the classroom. McKernan (1996) further explained that “action research aims at feeding the practical judgement of actors in problematic situations. The validity of the concepts, models and results it generates depends not so much on scientific tests of truth as on their utility in helping practitioners to act more effectively, skillfully and intelligently” (p. 16). In essence, theory is not independently developed and then applied; rather it is validated through teacher application.

Action Research as Methodology

The concept of practical application of research has existed in various forms and theories such as grounded theory, constructivism and pragmatism. The term action research was originally coined by Kurt Lewin in the 1970s. Considered the father of action research, Lewin developed a methodology and framework for action research that is still in use today (Lothian, 2010). Action research, as defined by Johnson (2008), is a systematic inquiry into your own practice. Mills (2003) further described action research as the systematic inquiry performed by educational staff for the purpose of gaining insight into how they teach and students learn. While there are varying scopes and definitions of action research, many include the use of a systematic approach. Lewin (1948) initially described this systematic approach as a cycle containing multiple steps that are performed recursively (repeatedly) as a means of refining the research outcome. This method has been further refined by other researchers, but typically includes four steps, labelled as Plan-Act-Develop-Reflect (Mertler, 2014). An example of such a recursive cycle is presented in Figure 1.1.

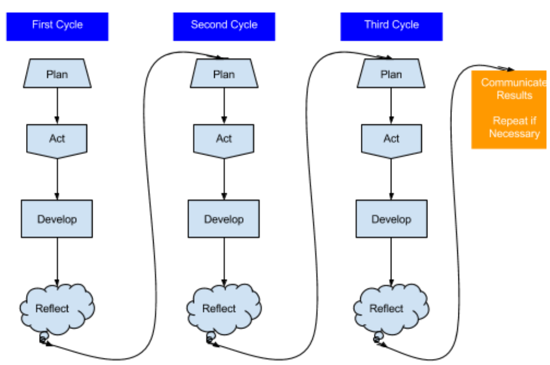

Figure 1.1. Explanation of the action research method through cycles and phases as redrawn from Reil (2010).

Action Research as a Conceptual Framework

Rojewski (personal communication, March 13, 2015) described a conceptual research framework as a lens comprised of ideas or theories through which we view our research. Action research employs a conceptual framework that informs how we reflect upon and develop our concepts or theories of learning (Lothian, 2010). Therefore, it is important to understand its foundational ideas and theories. After its initial inception by Lewin (1948), Stringer (2014) described action research as following a phenomenological approach with a focus on specific people, events, or problems and efforts to understand them better. This was further enhanced by the Science in Education movement which sought to understand more about education and educational theory through the use of the scientific method (McKernan, 1996). McKernan (1996) explained that action research is grounded in Dewey’s concept of inductive reasoning where individual cases are studied to find relationships. Focus on the individual was reinforced by the teacher-researcher movement in that prompted the idea that teachers should perform research within their classrooms and that such research can provide valuable insight into educational theory. The focus on the individual researcher and the study of pragmatic problems led to Zuber-Skerritt’s (2001) convergence of four theories to generate a conceptual framework that adequately addresses the various points of emphasis that action research has developed.

The Zuber-Skerritt Action Research Conceptual Framework

Mertler (2014) described the essential components of action research which included; its iterative nature, a focus on the reflective practitioner, a desire for improvement or change from current practice, and a systematic approach to solve problems. These concepts can be found in Zuber-Skerritt’s (2001) conceptual framework of action research, which were defined through grounded theory, personal construct theory, critical theory, and systems theory. Grounded theory, according to Glaser and Strauss (1967) established that theory can be developed from individual contexts by an alternating process of discovery, theory development, and testing. Much like action research, this theory is iterative, seeking to refine understanding through multiple cycles of discovery and testing (Zuber-Skerritt, 2001). Additionally, the framework's focus on contextual knowledge aligns with the focus on the practitioner as researcher. Personal construct theory (PCT) further focuses on the individual as a developer of knowledge within their context through the assumption that everyone is a personal scientist (Zuber-Skerritt, 2001). These personal scientists are capable of developing knowledge at different levels and are active constructors of knowledge rather than passive recipients. Not only does this theory enhances the contextual nature of action research, but also approves of the individual, the practitioner-researcher, as someone who is capable of developing educational theory and knowledge. Critical theory, Zuber-Skerritt (2001) argued, seeks to enact social change for the improvement of individuals or the environment. Such a theory aligns with the desire for change, renewal, and improvement of a teacher's practice. Finally, systems theory assumes that there are concepts of interrelatedness and systematic thinking. The concept of interrelatedness assumes that all things are connected or related to some degree; therefore, changes and reflections that practitioners make should be upon the whole teaching experience and not singular parts because these parts are inextricably related to other components that make up the whole of the educational experience. Additionally, systematic thinking involves developing solutions in a logically sequenced manner which addresses all the complexities of an environment (Zuber-Skerritt, 2001). Therefore, systems thinking requires researchers to take a holistic, systematic approach to problem-solving, which action research provides through the methodology of recursive cycles with clearly delineated steps. Action research also requires the researcher to reflect upon all aspects of the environment in order to improve. While this conceptual framework sets the stage for the use of action research and the theory surrounding its application, Herr and Anderson (2005) explained that action research also requires a context-relevant conceptual framework.

A Conceptual Framework for this Study

Zuber-Skerritt (2001) provided an initial framework for an action research study. Herr and Anderson (2005) explained that such a framework is sufficient for the implementation of action research, but a conceptual framework for the context of the research is also necessary. This study was guided by a conceptual framework comprised of Whitehead's Living Educational Theory and Kolb's Learning Cycle. Whitehead (1989) rejected positivist research as the only means of developing valid educational theory in exchange for the concept of a living educational theory (Lothian, 2010). He described the concept of a living educational theory as one that develops from the question "how do I improve my practice?" (p.41). This allows individuals to continually develop, revise, and improve their understanding of practice, while assimilating existing or new theories into their living theory. Whitehead and McNiff (2006) explained that this process is a contrast to standard social sciences research that focuses on an observer-centric approach to understanding. Rather, living educational theory moves researchers from spectators to practitioners. Each individual has developed and continues to develop their own theory or explanation for what they do and why. The living educational theory assumes that each person "already has their own tacit theory within themselves of how they should live, and they work collaboratively to make sense of what they are doing by talking through their ideas, and monitoring the process" (Whitehead & McNiff, 2006, p. 3). As teacher of nine years, I have developed and incorporated theories and beliefs regarding education and the teaching process. Some of these ideas and theories have been incorporated from my education as a teacher; some through practical experience. However, this living educational theory I have developed, as Whitehead and McNiff (2006) asserted, should be constantly discussed, analyzed, reflected upon, and modified as new information is presented and as I analyze my practice. Therefore, I employed the living educational theory as the basis for the reflection and revision of my teaching of engineering design.

The living educational theory provides a basis for the reflection and modification of my practice. However, as a technology teacher, I am not experienced in teaching scientific principles to students. Therefore, to best enhance my practice, I incorporated Kolb's learning cycles into my living educational theory as recommended by Muscat and Mollicone (2012). They explain that this four stage cycle provides a holistic approach to instruction as it encompasses all of Kolb's defined learning styles and provides a systematic approach to teaching new content which has been found useful by many teachers especially in the areas of science, math, and engineering. Because all students were incorporated in the educational process, the data from the research provided a more complete data set for analysis. Kolb's learning cycle is not the only educational theory that merits use in the teaching of engineering design. Denson and Lammi (2014) explained that Project-Based Learning (PBL) is a popular and widely accepted pedagogical approach. PBL is described by Markham, Larmer, and Ravitz (2003) as "a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed projects and tasks" (p. 4). Householder (2011) explained that PBL is best used in engineering design challenges that involve long-term, ill-structured problems. However, my study had shorter time constraints meaning is was not a completely ill-structured problem. Therefore, the Kolb learning cycle theory best aligned with the needs and implementation of this study. Additionally, some critics have asserted that there are problems with Kolb's theory in both predictive capability and its accuracy in correctly representing psychometric properties of intelligence. (Kolb, Boyatzis & Mainemelis, 2001). However, Kolb et al. (2001) stated that Kolb's learning styles and learning cycle were designed as self-assessments and were not intended to predict specific behavior. Even so, it is still close to similar intelligence inventories in its predictive capacity. Additionally, significant amounts of research have been performed since Kolb's development of the original learning styles and cycle. The concerns expressed in these studies have been incorporated in revisions of the theory over time (Kolb et al., 2001). Therefore, Kolb's learning cycles still provide a firm foundation for implementing an engineering design challenge.

Importance of Study

Although STEM is an emerging field of interest in teacher education, there are a number of companies and organizations that have developed resources for teaching these concepts. From lessons supplied on NASA's website to companies like Vex Robotics and Lego Robotics developing their own curriculum, there has been some progress in developing STEM education resources. So why did I conduct this study? Asunda (2012) asserted that, while there has been a push for the integration of STEM into the technology classroom, that it is unclear what specific concepts should be taught and how they should be taught. He further explained that engineering design is included in many of the relevant standards to science, mathematics, technology, and engineering and should be included in the technology classroom. Asunda and Hill (2007, 2008) further explained that there is a lack of research in the area of design optimization and analysis, especially when it comes to teaching these concepts in the technology classroom. This concern is echoed by Rowell (1999), Bennett (1999), and Cajas (2000). Wicklein et al. (2009) concur with this assessment and explain that the eclectic approach to technology education has led to some inclusion of engineering design, but without a clear and focused approach as to how such a concept should be taught. Kelley and Wicklein (2009) performed a study identifying technology teacher concerns related to teaching engineering design in the classroom. Two of the highest scoring issues were the inability to determine appropriate scientific and mathematics concepts to teach and the inability to find or acquire resources to adequately teach engineering design. Based on my own experiences in attempting to teach engineering design, I have found this to be true. Therefore, there is a gap in the research related to understanding how to teach engineering design in the technology education classroom and there is a lack of practical knowledge and resources in teaching this concept. This study attempted to not only provide insight into this area of technology education but also provide practical, useful resources in the form of curriculum which other teachers can implement into their classes.

CHAPTER 2 LITERATURE REVIEW

Understanding Engineering Design

There has been an increased interest in the incorporation of STEM (Science, Technology, Engineering, and Math) curriculum and concepts in education. This is directly related to the desire to not only emphasize and reinforce mathematical and scientific concepts, but to enhance student problem solving skills through engineering design. Yet, how is engineering design related to technology education and how could such concepts be integrated into a technology education course?

The Role of Engineering Design in Technology Education

Hacker, Burghardt, Fletcher, Gordon, and Peruzzi (2010) described technology as "the means by which humans modify the world to address their needs and wants" (p. 3). They further explained that science is "the observation of what is [while] engineering is creating what has never been" (p. 4). Technology, therefore, is a result of the combination of math and science. Booker-Dwyer's (2003) definition of technology education as an "integrated, experienced-based instructional program designed to prepare a population that is knowledgeable about technology – its evolution, systems, techniques, uses and social and cultural significance" (Technology Education section, para. 1) described how technology has been developed over time. However the link to engineering education was weak until we entered the 21st century. It was at this time that education shifted to an emphasis on STEM (Dugger, 1994). Since that time considerable resources have been directed at aligning these subjects as well as building interest in these areas. While federal programs have made a significant push for STEM education, Katehi, Pearson, and

Feder (2009) explained that the focus has been primarily in the fields of mathematics and science. They further described the engineering education field as a work in progress that is slowly gaining traction in schools. Dugger (1994) explained that engineering design is often used in technology education because “both engineering and technology treat solving practical problems as their philosophical nucleus” (p. 7). Additionally, professional organizations such as the National Center for Engineering and Technology Education (NCETE) have expressed the value of integrating engineering design into technology education. The importance of incorporating engineering design into the technology education curriculum has been researched by Wicklein (2006) through which he developed multiple reasons for the value associated with its incorporation into technology education.

The Value of Engineering Design

While the design process and its involvement of science, technology, engineering, and mathematic principles seems to be a useful tool to imlement into the technology education classroom, the question remains as to the value of its implementation. Wicklein, Smith and Kim (2009) explained that there are a number of proponents and a variety of methods for incorporating problem solving methodologies into the technology education curriculum. The value of teaching engineering design can be seen from the student as well as technology education perspective. Proponents of engineering design education such as Katehi et al. (2009) describe one of the most promising improvements for students is their increased ability to apply mathematic and scientific concepts both in their respective classes, as well as outside of these traditional settings. Householder and Hailey (2012) performed a study which encompassed literature and experiences of incorporating engineering design of various researchers in the field. While they concurred that these challenges help students understand and apply mathematic and scientific concepts, they explained that this value is further enhanced by the ability of students to practically apply these ideas and the self-efficacy that comes with understaning and solving problems of this nature. They further explained that the practical application of these concepts, the ability to think systematically, and the development of engineering thoughts and habits were all of value to students as they can use these tools to enhance their understanding of the world around them as well as in their classes and future education.

From a technology education perspective, Wicklein (2006) provided five reasons to support the curricular value of teaching the engineering design process.

Reason 1

Wicklein (2006) asserted that engineering design is more understood and valued than technology education by the general populace. In this first reason, Wicklein (2006) explained that there is confusion as to the purpose and nature of technology education. This is evidenced by the tremendous amount of literature and concern expressed by professionals in the field that technology education lacks a coherent strategy for relevance (Martin & Ritz, 2012). However, the concept of engineering and even the term itself has a high level of name recognition (National Academy of Engineering, 1998). While people may not necessarily be able to identify the steps of the engineering design process, they understand the importance of engineers within society and attach more value to programs such as STEM which incorporate engineering. While this may seem like a conceited push by technology educators, Brown and Borrego (2013) explained that it actually provides a greater benefit by improving technological literacy amongst students through increased enrollment based on the perceived value of engineering. Also, it introduces students to engineering and other new career tracks that they may not have previously considered as described in Wicklein's (2006) Reason 5.

Reason 2

Engineering design elevates the field of technology education to higher academic and technological levels.Wicklein's (2006) assertion is that the general lack of understanding by the outside population is only exacerbated by the lack of understanding within the school environment including administrators and guidance counselors who view technology education as either a lower-tier elective or classes that are best attributed to students who are not college-bound. The United States Department of Education (2012) report on career and technical education (2012) explained that this perception is due to the lack of high quality, directed programs which align with further education and the needs of employers. The report explained, however, that career and technical education has the propensity to provide a substantial benefit to students through its inclusion of engineering principles such as the engineering design process. This could help elevate the educational rigor and quality of courses and thus help improve the perception of those both inside and outside the school (Daugherty et al., 2010).

Reason 3

Engineering design provides a solid framework to develop and organize curriculum. Wicklein (2006) explained that engineering design is a multi-faceted platform that can be incorporated over several courses and thus provide direction for technology education. Currently technology education contains a mix of seemingly unrelated courses. the implementation of teaching the engineering design process over a number of courses and years can provide a cohesive system of courses that can readily be tied into other levels of coursework in mathematics and science (Wicklein, 2006). Daugherty et al. (2010) explained that cross-curricular inclusion is often difficult due to standards, testing requirements, and stringent content requirements. However, they asserted, the unique interrelatedness of science, technology, engineering, and mathematics allows for the tailoring of cross-standard and cross-curriculuar instructional content. Some states such as Georgia already have begun the work of developing courses which align with this process and can be readily implemented (Denson, Kelley, & Wicklein, 2009).

Reason 4

Engineering design provides an ideal platform for integrating mathematics, science, and technology. In recent years, there has been a push for STEM to become an integrated aspect of education, especially in high school settings (Daugherty et al., 2010). While there are STEM school certifications and other STEM-related standards, the underlying concept is the inclusion of each of the STEM content areas with the others. With the incorporation of engineering design into technology education, the emphasis of STEM can be turned towards the inclusion and enhancement of mathematic and scientific skills within the technology education classroom as these are prerequisite for solving engineering design problems (Daugherty et al., 2010). This inclusion serves to even further enhance the effects of Reasons 1 and 2 as the rigor, quality, and variety of concepts being taught in technology education courses will increase (Wicklein, 2006).

Reason 5

Engineering provides a focused curriculum that can lead to multiple career pathways for students. The end result of a successful educational experience for students should be the aspiration or at least introduction to new careers and educational possibilities in further education (Daugherty et al., 2010). Wicklein (2006) described this final reason as a comprimise in which students that are interested in both general education as well as career and technical education can participate and learn about technology and engineering. The structure of courses as mentioned in Reason 3 allows students to participate from a college-bound as well as technical perspective and such curriculum can be modified as necessary to incorporate and improve either type of student (Wicklein, 2006). Such coursework has the added benefit of introducing students to the field of engineering which has seen dramatic decreases in enrollment and interest in previous years (Brown &Borrego, 2013). The need for engineers and problem solvers in our society stands without question and yet we are not seeing a reciprocal interest in the engineering field. By including engineering design into technology education curriculum, teachers could provide a renewed interest in a field which needs greater enrollment and participation (Daugherty et al., 2010).

A Professional Perspective

In their research into curricular value of this inclusion of engineering design in technology education, Gattie and Wicklein (2007) surveyed a number of professional educators to determine their impressions. A comparison of their results and the five reasons is seen below.

Table 2.1

Wicklein's (2006) Five Reasons vs. Professional Perspectives (Gattie &Wicklein, 2007)

Reason from Wicklein (2006)	Professional Response	Percent (%) Agreement with Statement
Reason 1	Clarifying the focus of the field	93%
Reason 4	Providing a platform for integration with other school subjects	96.7%
Reason 2	Elevating the field to higher academic levels	92.7%
Reason 3	Improving instructional content	88.4%
Reason 5	Increasing student interest in mathematics and science	89.3%
Reason 5	Providing additional learning opportunities for students	94.4%

There is a significant overlap in agreement between teachers in the fields of engineering and technology education and Wicklein's (2006) assertions. Engineering design has seen an increase in interest in the technology education literature as a means to enhance technology education and improve student education in general (Lewis, 2005). As Wicklein (2006) asserted there are a number of reasons for this renewed interest in engineering. While others may have various reasons for wanting to implement engineering design into technology education, the benefits of elevating the field and student expectations and outcomes is a tremendous benefit which should not be overlooked (Lewis, 2005). While the inclusion of the engineering design process is important in technology education, Smith (2006) explained that there are a variety of models and methods for teaching this process. Therefore, it is important to define what the engineering design process is and the critical components which should be included in its teaching.

The Relationship of Technology and Engineering Education

While the first thought that comes to mind when hearing the term technology more than likely pertains to a computer, smart phone, or other electronic device, technology encompasses a much broader field than just these objects. Feisel and Rosa (2005) described the purpose of engineering as “harnessing and modifying the three fundamental resources that humankind has available for the creation of all technology” (p. 121). The University of California Museum of Paleontology’s Understanding Science site explained that

> engineering involves applying scientific and mathematical knowledge to design and operate objects, systems, and processes to help us solve problems or reach goals. These processes often involve developing new technologies. Though we usually associate the word technology with things like microchips and satellites, in fact, the concept applies to a broad range of innovations. From the simplest of tools (like a chimpanzee's termite fishing stick), to practical problem-solving (like adding fluoride to water to help prevent cavities), anything we make or do that changes the natural world for our own purposes counts as technology. (n.d.)

The Florida Agricultural and Mechanical University (“Technology Education”, n.d.) further described technology education’s inextricable relationship to engineering in its definition as the “practice of educating students about different technology and engineering concepts as they relate to the ‘human made’ world.” Put in simpler terms, engineering is the application of science and mathematics to solve problems (“What is Engineering?”, n.d.). Based on these definitions, it becomes clear how engineering and technology education are linked; both involve problem solving in a systematic manner. The International Technology and Engineering Educator’s Association (ITEEA, 2007) explained the importance of systems in technology and engineering as their basic building block. Therefore, technology and engineering education not only include hands-on experience in problem solving but inevitably teaches the application of science and mathematics to these problems in a systematic manner. However, there are some differences in the technological design process and the engineering design process.

Technological Design Process vs. Engineering Design Process

Smith (2006) explained that there are a variety of models for the process of designing solutions to ill-defined problems. Two such processes are the technological design process as delineated by Standard 9-H of the *Standards for Technology Literacy* (International Technology Education Association, 2002) and the engineering design process. Gattie and Wicklein (2007) explained that these processes may seem similar at first glance, but that the analytical and optimizing components are not present within the technological design approach, thus limiting the student’s ability to predict the result of their solutions. Rather, the technological design process substitutes the use of analysis with prototyping (Gattie & Wicklein, 2007). Table 2.2 demonstrates these differences side-by-side.

Table 2.2

Side-by-Side Comparison of Design Processes

Engineering Design Process	Technological Design Process
Identify the need	***Not Present***
Define problem	Define problem
Search for solutions	Research and generate ideas
Identify constraints	Specify constraints / explore possibilities
Specify evaluation criteria	Identify criteria
Generate alternative solutions	Select an approach
Analysis	***Not Present***
Mathematical predictions	***Not Present***
Optimization	***Not Present***
Decision	***Not Present***
Design specification	Develop a design proposal / Build a model or prototype
Communicate design specifications	Communicating results

Kelley (2010b) explained that the lack of optimization and analysis stages, as shown in Table 2.2, greatly hinders the technological design process and results in the use of guessing rather than sound predictive analysis. Robert Wicklein (personal communication, November 11, 2013) explained the flaw in this process through the illustration of building a bridge. He explained that, when civil engineers build a bridge, they do not build it and then drive larger and larger trucks over it until it collapses to determine its weight tolerance. Rather, they use mathematical models and the scientific properties of materials to predict the allowed weight and design an optimal bridge which can withstand the required rigors of heavy trucks driving over it. However, the technological design process omits these steps in favor of prototyping which is akin to driving the larger and larger trucks over the bridge.

The need for the steps of analysis, mathematical predictions, and optimization before making a decision or prototyping is well documented and supported by Wicklein (2006), Gattie and Wicklein (2007), Householder and Hailey (2012), Kelley (2010b), Asunda and Hill (2007), Asunda (2012), Hill (2006), and Hailey, Erekson, Becker, and Thomas (2005). Yet the technological design process does not incorporate these aspects. However, they are not the only ones who omit these steps. Educational content developed by companies such as Lego (Lego Engineering, 2013) and Vex Robotics Curriculum (n.d.) omit these steps. Organizations such as NASA (Hoban & Delaney, n.d.) even omit these steps in favor of a more simplistic model that does not require mathematical and scientific modeling. Therefore, in light of the overwhelming support of the inclusion of such steps and the lack of educational resources which such content included (Gattie & Wicklein, 2007), this study approached the design challenge put forth through the teaching and implementation of the engineering design process.

The Engineering Design Process

Eide, Jenison, Mashaw, and Northup (2002), explained that design is simply a "structured problem solving activity" (p. 55). They further explained that a process is step by step changes that work towards a desired result. Smith (2006) explained that there are a variety of models, steps, and representations of the engineering design processes. Wicklein, Smith, and Kim (2009) stated that there has been an increased interest in such a process. In particular, they explained that the engineering design process has garnered attention for its possible applications in technology education. However, Smith (2006) described a disparity as to the specific steps, or process, of engineering design and its application in education. One popular model of the engineering design process proposed by Hynes, Portsmore, Dare, Milto, Rogers, Hammer, and Carberry (2011) was developed in conjunction with the Massachusetts State Department of Education and includes the steps commonly found in different engineering design process representations. However, this model excluded the steps of analysis and optimization, critical components of the engineering design process (Hill, 2006). Therefore, the Eide et al. (2002) model was selected as it has a number of the steps as explained by Hynes et al. (2011) but also includes the aforementioned missing steps. This model was identified as an appropriate model including all the necessary components of the engineering design process by Gattie and Wicklein (2007).

Step 1: Identify the Need

In this first step, Householder and Hailey (2012) described that students should ideally be able to identify their own needs related to issues they confront in life or see in the world. They emphasized the importance of relevance to the student in the design challenge rather than simply an arbitrary concept or idea chosen by the teacher. This concept is closely related to the practice of professional engineers who solve problems that people encounter in everyday life (Abarca et al., 2000). Eide et al. (2002) explained that engineers tend to identify needs through "a lack or shortage of something that we consider essential or highly desireable" (p. 86). Asunda and Hill (2007) echoed the idea that identifying the need should have societal implications and address a concern or problem of individuals. The *College of Engineering Design Handbook* (n.d.) published by the University of Georgia named this step the statement of work, and explained that it puts client needs into a framework which helps guide the design process.

Step 2: Define the Problem

Asunda and Hill (2007) defined this step as describing the nature of the question to be solved. Eide et al. (2002) added that, at this time, the problem in its entirerty is discussed, described, and finally defined. They cautioned that, during this step, it is tempting to define a solution without proceeding through the remaining steps. To avoid such issues Eide, et al. (2002) explained that students should begin by generating a broad definition based on needs rather than objects. This is known as systemic analysis of the problem, a requirement of professional engineers (Khisty, Mohammadi, & Amekudzi, 2012).While the engineering design process as a whole is used to systematically solve problems, Khisty et al. (2012) explained that being systemic in problem solving is looking at the problem in a holistic manner, or broadening the focus of the problem to not only include the individual engineer, but all stakeholders who could be possibly impacted by the problem. They further explained that both systematic and systemic problem solving are key concepts that engineers practice in both the solving of a problem as well as its definition. Abarca et al. (2000) added to this concept the idea that problem statements should be generalized and should not include solution elements. Additionally, they explained that such statements should be written in functional terms or using verbs acting on nouns. They further emhasized the importance of simplicity in defining the problem. Eide et al. (2002) also explained that once students develop a general problem definition that they ensure that they are addressing the cause and not the symptom. In the Electrical and Computer Engineering Design Handbook, Staniewicz (n.d.) described this as root cause failure analysis which Mobley (1999) outlined as a process for seeking the causes of issues rather than generating solutions to symptoms that arise. As a final step in reviewing the problem definition Eide et al. (2002) explained that the students should ensure that they are not solving the wrong problem through omission of factors such as the environment and attitudes of the stakeholders. *College of Engineering Design Handbook* (n.d.) described problem definition as the most critical aspect of engineering design as all other steps are developed based on the defined problem.

Step 3: Search

Householder and Hailey (2012) clarified that before jumping into solving the problem, students should perform research on the area in which the problem is situated. They further clarified that students need to comprehend that research is critical to developing a better understanding of the problem as well as developing the best solution possible. Eide et al. (2002)

described this step as documenting what is known as well as what needs to be understood about the problem. They explained that information can come from prexisting knowledge and solutions, the internet, libraries, the government, professional organizations, journals, and experts in the field. In essence, the students are conducting a shorter version of the literature review performed by researchers. Abarca et al. (2000) further pronounced the importance of this process as not completing proper and thorough research could lead the student to generate solutions which already exist or violate laws or statutes. They further explained that such research should include the patent searches to ensure that infringement does not occur.

Step 4: Identify Constraints

As a part of the research into the problem area, students will identify constraints on the design solutions. Eide et al. (2002) described constraints as “a physical or practical limitation on possible solutions” (p. 94). Householder and Hailey (2012) explained that constrains limit the possible number of solutions and can come from various sources such as “cost, safety, culture, environmental impact, and client needs” (p. 24). Dym and Little (2014) further described the process and importance of developing constraints. They explained that constraints are typically yes or no type questions, such as: can the solution be a conductor of electricity? Additionally, they explained that constraints “limit the problem space [and force] the exclusion of unacceptable alternatives” (p. 67). Eide et al. (2002) explained constrains could be such issues as the final cost not exceeeding fifty dollars in order for the product to remain competitive, the solution being required to operate on normal 120V househould outlets, and the physical size of a laptop not exceeding reasonable dimensions. Dym and Little (2014) also explained that often times students can experience difficulty when balancing constraints with their designs, and therefore may require more teacher assistance in this area.

Step 5: Generate Evaluation Criteria

While constraints could be considered a need or requirement, criteria and are defined as “desireable characteristics of the solution which are established from experience, research, market studies, and customer preferences” (Eide et al., 2002, p. 95). In other words, criteria involve what we want a specific solution to do or achieve. Eide et al. (2002) described criteria as being qualitative in its assessment rather than quantitative constraints. Khandani (2005) explained that this step involves determining what criteria the solution will need in order to be considered successful. The *Next Generation Science Standards* (NGSS Lead States, 2013) described this step as generating “prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts” (HS-ETS1-3). This, as in the problem definition, is a point where systemic understanding of stakeholders’ concerns becomes increasingly important (Verganti, 1997). An example of a recent product release is the Apple Pencil. By its very name and purpose, this device must meet certain size requirements as well as be able to operate within the Apple ecosystem of products. These are two examples of possible design constraints for this product. However, criteria, such as how well it imitates a pencil, the features that are encompassed in the design, its aestheics and ergonomics; are less about the physical limitations and more related to its performance and acceptance as an acceptable solution to the stakeholders. Dym and Little (2009) explained that when developing and organizing these criteria, the creation of a design matrix is a useful practice which helps organize and prioritize their thoughts. A design matrix aligns the criteria or constraints developed earlier and weights their importance. Each of the concepts or design solutions is rated based on how well it meets the specified criteria. Figure 2.1 is an example of a design matrix, sometimes called a decision matrix, which was developed in

Microsoft Excel based on a similar design matrix from MIT's Open Courseware ("Design Process"). Such a tool allows students to visually represent and defend their decision in selecting the best solution. (Householder & Hailey, 2012).

		Concepts					
Criteria	Weight	Rating	Rating x Weight	Rating	Rating x Weight	Rating	Rating x Weight
Total Score							

Figure 2.1. Design (decision) matrix used to evaluate possible solutions.

Step 6: Generate Alternative Solutions

Eide et al. (2002) describe this step as the creative part of the engineering design process where students begin to imagine new ideas or solutions to the problem. Abarca et al. (2000) named this step identifying alternative solutions or invention and echoed Eide et al. (2002) in their description of this part as both creative and stimulating to students. Householder and Hailey (2012) explained that, in this step, students should generate as many ideas as possible as this will lead to a better solution. They further explained that teachers should encourage multiple solutions and discourage fixation on a single solution. In my class, I refer to this step as "No evaluation with generation." This means that students cannot evaluate or pick favorites when generating ideas for design, but that all solutions bear equal weight and due diligence until the next step.

Step 7: Analysis

“Analysis involves the use of mathematical and engineering principles to determine the performance of a solution” (Eide, et al., 2002, p. 102). Cooper, Zarske, and Carlson (2008) described analysis as the step which differentiates trial and error testing from engineering design. Cooper et al. (2008) define engineering analysis as “the internal guidance of a project. It can be described as the breaking down of an object, system, problem or issue into its basic elements to get at its essential features and their relationships to each other and to external elements” (para. 5). Kelley (2010b) further descibed analysis as “when mathematical models and scientific principles are employed to help the designer predict design results” (p. 18). He explained that this application of mathematics and science as well as constraints and criteria to the possible solutions are predictive analysis and optimization, two critical components of the analysis step.

Predictive analysis. Little, Dym, and Orwin (2013) explained that mathematical modeling allows engineers to predict the behavior of designs before having to actually use physical resources. They described mathematical modeling as the use of equations and theory to produce an expected outcome of a design. Additionally, they explained that the importance of this step lies in its ability to save time and resources as well as avoid over-designing of solutions. Merrill, Custer, Daugherty, Westrick, and Zeng (2008) further described this step as predicitive analysis, and that it includes the use of mathematic and scientific principles to determine if a given solution will perform as desired. In addition they state that many engineers will perform this step before prototyping to save time, money, and resources. They described this process of “thinking before acting” (p.2) as critical to adequately applying the engineering design process. Daugherty (2011) described prediction as a critical component of engineering design as it becomes the basis for further decision making within the design process. He furthered explained that the purpose of prediction is to make good decisions in relation to the design. The proper use of mathematical prediction can be seen in engineering successes as well as failures. Cooper et al. (2008) explained that the first aeronautical engineers lacked the appropriate predictive models and tools to appropriately assess their designs, leading to design failure and even death of the engineer. Asunda and Hill (2007) concluded that the inclusion of such principles is an important aspect of the engineering design process as it allows the engineer the ability to accurately predict the behavior of a particular solution.

Optimization. Kelley (personal communication, July 17, 2015) explained that optimization is an important part of the engineering design process and describes it as using the constraints and criteria established to determine the optimal or best solution. He further explained that optimization is often considered a part of the analysis step as it narrows the possible solutions much like analysis. Additionally, he explained that this step is performed before design specifications or construction begins. Gomez, Oakes, and Leone described optimization as "doing the most with the least" (as cited in Kelley, 2010b). Additionally, Merrill et al. (2008) explained that design optimization seeks to maximize factors such as strength, productivity, reliability and efficiency through the use of mathematical models or formulas. Kelley (2010b) explained that the end result of design optimization is the best possible solution(s) for the proposed problem. He explained that, while predictive analysis determines the possible outcome of a solution, optimization involves selecting a solution through weighing it against the other possible solutions and the developed constraints and criteria. Kelley (2010b) explained that one of the best ways for students to understand the concept of optimization is through real-world applications such as Lindbergh's historic flight from New York to Paris. Eide et al. (2002) explained that some "performance functions can be defined mathematicall [and that in this case] an optimum solution can be obtained mathematically" (p. 95). However, they also explained that the mathematical and scientific concepts can often fall outside of the understanding of pre-engineering students. Therefore, they offerred that students can apply this process through the evaluation of their solutions based on the criteria and constraints that were determined in previous steps.

Step 8: Decision

Eide, et al. (2002) described the decision step as incorporating the analysis, prediction, and optimization results to determine the best solution which meets the needs of the problem or client. They explained that, through the process of optimization, there will likely be multiple solutions available. Engineers must select the solution with the understanding that there will be strengths and weaknesses of each possible solution, and that the engineer must consider these trade-offs. Additionally, Householder and Hailey (2012) explained that "defending solutions is essential in the design process. Students need to compile a log documenting their work, recording their decisions and the bases for those decisions" (p. 26). Simply put, students should be able to defend their work based on their completion and documentation of the process. Therefore, making the decision to go with a specific solution is not the only aspect of this process.

Step 9: Design Specification

Design specification is where the engineer develops documents which describe the construction, materials, and other physical characteristics of the design (Eide, et al., 2002). Eide, et al. (2002) described this step as clearly defining the solution to others. Pugh (1991) explained that a document called a product design specification (pds) is developed during this step and contains such information as performance (life in service), operating environment, weight, size, cost, aesthetics, and adherence to standards or specifications. This is an important practice of professional engineers who will often be required to present their designs to stakeholders (Householder & Hailey, 2012). However, in addition to a written specification of the design, Asunda and Hill (2007) identified the construction of a prototype as an important aspect of the engineering design process. Householder and Hailey (2012) explained that prototype construction in an engineering design challenge is important because it is a tangible representation of students' design efforts and thus is one of the more rewarding stages for the student. Wicklein et al.'s (2009) study also drew the conclusion that the hands on nature of prototyping as a useful exercise in teaching the engineering design process. While prototyping has a number of benefits, there are some constraints which could limit the ability to build a prototype such as time and resources (Kelley & Wicklein, 2009c). Therefore, design specifications can act as a blueprint for building a finalized design or even a prototype when the resources are not available to do so (Eide et al., 2002).

Step 10: Communicate Design Specifications

The generation of a complete solution is not the final step in the engineering design process, rather, engineers are often required to present their designs and findings to the customer or other stakeholders in the project (Householder & Hailey, 2012). Eide et al. (2002) described the process of communication for engineers as selling the design, generating a written report, and presenting orally their findings. They explained that selling the design involves being able to discuss and persuade individuals on the merits of their solution versus others in the marketplace. In terms of the written report and oral presentations, one of the essential tools in presenting the solution and findings of the engineer is the engineering notebook (Kelley, 2011). Asunda and Hill (2007) found that a theme important amongst engineering teachers and professional engineers was the use of documentation throughout the engineering process through the use of an engineering notebook. Kelley (2014) further explained that an engineer's notebook captures the ideas thoughts, drawings, and other content related to the design process in written form. He explained that such documentation provides valuable insight into the student's process and thus should be a component used to evaluate their solution as well as in the redesign of the solution if necessary. Householder and Hailey (2012) also recommended the use of written communications such as an engineering notebook to help students organize their thoughts and present their materials to a group which not only assists in developing their communication skills but also to help them reflect on their ideas.

Mathematics and Science in Engineering Design

While some curriculum exists that teaches the engineering design process, it often excludes mathematic and scientific principles. Asunda (2012) described science as "a process of producing knowledge; the process depends on making careful observations of phenomena in the natural world and inventing theories for making sense out of those observations and therefore develop in students a set of predetermined beliefs about their natural environment" (p. 47). He further explained that mathematics is "the study of patterns or relationships." (p. 47). While they are their own separate fields, they are inextricably linked and reinforce each other through discovery and observation (Asunda, 2012). Daugherty (2011) explained that much of the recent emphasis on STEM education has been in the science and mathematics departments within K-12 education, but that technology and engineering education can provide an equally useful role in reinforcing these concepts through the process of teaching engineering design. Merrill et al. (2008) explained that a critical aspect of engineering design for professional engineers was predictive analysis. They explained that "engineers apply mathematical and scientific principles to solve problems. The introduction of these tools into the analytical stage of the design process represents an indispensable part of engineering design" (p. 49). They further explained that this predictive element is used to determine whether or not a path will have a possibility to lead to success. By using these optimizing tools, they are able to mitigate wasteful or unnecessary action and thus save resources and time. This is echoed by Asunda and Hill (2007) who explained that the application of mathematics and science falls into the predictive and optimizing themes which are critical to engineering design. Kelley (2010b) described these themes as design analysis (predictive element) and design optimization.

> The analysis stage of the engineering design process is when mathematical models and scientific principles are employed to help the designer predict design results. The optimization stage of the engineering design process is a systematic process using design constraints and criteria to allow the designer to locate the optimal solution. (p. 18)

He further explained that these steps should be performed before the creation of prototypes. Hayes (1989) concurred and described optimization and analysis as occurring in the planning environment or section of the engineering design process rather than the task or execution environment. He furthered explained that the location of these tasks in the planning environment has specific advantages. One such benefit is the ease of change and flexibility of design. It is also inexpensive to implement such changes. Lewis (2005) explained that "conceptual design is within the purview of technology education [however] analytic design poses a challenge" (p. 48). He describes this analytical or optimizing step as a "black box" (p. 48) where the best design is generated using mathematical and scientific principles. While previously such concepts have not been taught, Lewis (2005) explained that there are merits for the inclusion of such principles into technology education. Childress and Rhodes (2006) echoed the importance of these aspects in engineering education through their study which ranked engineering analysis as the third highest area of importance to engineering educators amongst the various areas of engineering education. Additionally, the respondents rated highly the need for students to apply mathematics and science to engineering designs as well as accessing necessary technologies to assist in design. Based on this understanding of the engineering design process, how should it be taught in the technology education classroom?

Essential Components of an Engineering Design Challenge

While there has been a push within technology education to incorporate engineering design, there was not a clearly delineated set of criteria or components that an engineering design unit of instruction should include (Denson & Lammi, 2014). Based on this gap in literature and understanding, the National Center for Engineering and Technology Education (NCETE) requested that research be performed on ascertaining what critical features would be included in an engineering design challenge or unit of instruction (Denson & Lammi, 2014). Householder (2012) explained that the spur for this research "began with a simple, straightforward question, ―What are the requirements for a good engineering design challenge? Matthew Lammi, then an NCETE fellow at Utah State University, addressed the question to Julia Ross, University of Maryland Baltimore County, who was telling a group of NCETE fellows about her success in engaging high school technology students and their teachers in authentic engineering design challenges" (p. 1). Householder (2012) further explained that the overwhelming response provided a plethora of ideas. Therefore, the NCETE invited six position papers from experts in various educational fields who had significant experience in researching engineering design in the classroom. Denson and Lammi (2014) synthesized their points into four categories or areas of consideration for engineering design challenges. The author's points in relation to Denson and Lammi's (2014) categories can be seen in Table 2.3.

In regards to each of the categories which Denson and Lammi (2014) described, there is some common agreement. This overlap can be used to generate a framework for what concepts need to be addressed when creating an engineering design instructional activity.

The first category, situating engineering design in the curriculum, many of the researchers were in agreement that engineering design activities should have some tie to standards in the various fields in which they are employed. However, the extent to which students discover these standards through their own problem definition or have the standards built-in to the activity is not entirely agreed upon.

Table 2.3

Comparison of Invited Positions vs. Synthesized Categories by Denson and Lammi (p. 5, 2014)

Denson & Lammi Categories	Situating engineering design in the curriculum	Sequencing the engineering design experience	Selecting appropriate design challenges	Assessing the engineering design experience
Author				
Jonassen (2011)	The teacher should present initial specifications and goals which align with curriculum	Problems fall on a continuum of well-structured to ill-structured	Students have learned to solve well-structured problems, so consider student motivation and support	Students should be able to determine based on criteria when a design satisfies requirements
Hynes, et. al (2011)	Engineering design projects should include relevant mathematic and scientific principles	Students should start with well-structured and move to ill-structured	Challenge should re-enforce students' process skills	Not discussed
Carr and Strobel (2011)	Problems should be integrated with existing standards, especially in math.	Problems should be concrete and move from novice to expert in steps.	Problems should have authentic or real world context for the students.	Evaluation should be on clearly defined standards.

Denson & Lammi Categories	Situating engineering design in the curriculum	Sequencing the engineering design experience	Selecting appropriate design challenges	Assessing the engineering design experience
Author				
Schunn (2011)	Design challenges should involve systems that emphasize science learning goals.	Challenges are integrated with current curriculum to emphasize concepts being taught within the classroom.	Design should allow for flexibility in choice of target goals and should be focused on helping society.	Requires reflective presentation of solutions rather than just working prototypes.
Eisenkraft (2011)	Challenges are tied to relevant content in a Physics class where each challenge is related to a unit of instruction.	Start with simple challenges and build in complexity as mastery occurs	Challenges should engage student interest and have multiple possibilities for unique outcomes.	There should be a means for grading the outcomes
Sneider (2011)	There should be a relationship between the design challenge and established standards	Sequencing of challenges and information. Type of problem (ill or well structured) is dependent on student knowledge	Based on age level and understanding of concepts, should be age and intellect relevent	Not mentioned

Sneider (2011) provided an example of how sequencing works within the engineering design challenge. He explained that students at different age levels from elementary all the way to high school can participate in the same type of activity, however, the terminology, depth of knowledge covered, and complexity of requirements can increase as student age and experience increases. This sequencing is also explained through the concept of ill-structured versus well-structured problems. Hynes et al. (2011) explained that well-structured problems are typically easier for students to comprehend and to have success at solving and thus are a good starting point for engineering design challenges. This is especially true of students do not have experience in problem solving strategies or the engineering design process. Jonassen (2011) conurred with Hynes et al. and added that many students can become quickly disillusioned or frustrated with challenges that lack the appropriate support level from the teacher. Eisenkraft (2011) described sequencing as moving from simple to incrementally more complex challenges or the process of moving from a novice to a master and that such a process takes multiple iterations of design challenges.

Selecting the design challenge can be difficult, especially when considering standards and difficulty level as mentioned in the previous two categories. However, nearly all six researchers concurred that choosing design challenges that were relevant to the students has far greater impact on the individual in both interest and perseverance. Schunn (2011) took this real world focus a step further as he described the need to make problems relevant to society rather than just the student. He asserted that the focus of many students' problems tend to be something that they themselves want or need. He argued, though, that real-world engineers must have a more systemic view, or that they must look at the entire context of the problem, and not merely their own interests. Additionally, engineers must be able to understand not only the technical aspects of a design, but the cultural, aesthetic, and even psychological implications of products. As an example, he described a problem in which students developed a product for women in Africa who had AIDS. He explained that the women would breast feed and pass on AIDS to their children in this manner. However, there is a strong psychological concern for the women of using solutions such as formula because it immediately identifies the woman as infected, thus causing social harm. Developing a solution to such a problem is not only a worthwhile cause, but also helps students to widen the perspective on the process of designing a solution.

In terms of assessment, there was little in the way of consensus in how such activities should be graded. The use of presentations, documentation, and grading based on the standards presented as part of the activity were all touted as possible assessment methods. Of the four categories, this was the weakest in terms of content and support. Many of the researchers were focused more on the richness of the experience and students being able to demonstrate engineering behaviors (Sneider, 2011) than in formal assessments. Many did mention that some type of documentation of steps and a final presentation or accountability for a completed solution was a necessity. However Denson and Lammi (2014) were not the only researchers to determine key concepts which should be included in engineering design activities.

Childress and Rhodes Essentail Components to a Design Challenge

Taking the components of a design challenge a step more specific, Childress and Rhodes (2008) conducted a Delphi study to determine exactly what components should be included in an engineering design challenge. Through working with a panel of engineering teachers and experts, they determined that engineering projects should contain aspects of “engineering design, application of engineering design, engineering analysis, engineering and human values, engineering communication, engineering science, and emerging fields of engineering” (pp. 7-8). However, Childress and Rhodes (2008) did caution that while these aspects were considered important attempting to include all of them in the curriculum of a class could crowd out the actual application and thus cause a lack of student interest. Based on this recommendation, this study focused on five of these areas.

Engineering Design

Childress and Rhodes (2008) explained that teaching engineering design contains multiple aspects such as understanding the iterative nature of the design process and the importance of creativity in designing solutions. This is confirmed by Asunda and Hill’s (2007) study which found that the engineering design process is a core theme which should be taught in engineering courses. This is also in alignment with the *Standards for Technological Literacy* (International Technology Educators Association, 2007) standards 8, 9, and 10. Table 2.4 shows each of these standards and how they were met by this study.

Table 2.4

Standards and Their Application

Standard	Explanation	Application
8	Students will develop an understanding of the attributes of design	Taught as part of the introduction to the unit of instruction and applied and reinforced throughout
9	Students will develop an understanding of engineering design	Taught as part of the introduction to the unit of instruction and applied and reinforced throughout
10	Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving	Taught in the explanation of the challenge and reinforced through student action and optimization.

This alignment with standards also coincides with Denson and Lammi's (2014) essential components of engineering design.

Application of Engineering Design

Childress and Rhodes (2008) take the teaching of engineering design a step further through its application which includes identifying problems that could be solved through engineering design and through steps such as optimization, analysis and testing. Kelley (2010b) concurred with the importance of optimization as a step in the engineering design process. Asunda and Hill (2007) also found the concepts of identifying problems and analysis within their core themes expressed by engineers. These concepts are also addressed in the *Standards for Technological Literacy* (ITEA, 2007) through standards 8 and 9. This study used Kolb's Learning Cycle as described later to introduce and define the problem as well as provide the opportunity for application of optimization and analysis through the challenge provided to the students.

Engineering Analysis

This component specifically addresses the use of models to describe the problem as well as the application of mathematic and scientific principles to the engineering design process (Childress & Rhodes, 2008). Mentzer (2011) as well as Asunda and Hill (2007) identified these concepts as critical to teaching engineering design. Wicklein (2006) even provides the inclusion of mathematic and scientific skills as one of his five reasons for the incorporation of engineering design into technology education. Further, Gattie and Wicklein (2007) described the engineering design process as having an “analytical” (p. 10) component which applies predictive analysis to solutions. They also found that engineering teachers identified this as an instructional need for engineering courses. This study incorporated engineering analysis through the teaching and calculation of ballistic trajectories to hit a target at a specified distance and height. Additionally, to assist in student understanding and modeling of the problem, the students were introduced to the concept through the creation of trajectories using footballs and water balloons which will be explained in chapter 3. The importance of these concepts are also expressed by the *Standards for Technological Literacy* (ITEA, 2007) in Standard 2, where they explained “students should have opportunities to use simulations and mathematical modeling, both of which are critical to the success of developing an optimum design” (p. 41). The use of analysis and optimization fall within Denson and Lammi’s (2014) point that engineering design challenges should be appropriate to the age of the students as well as be grounded in real-world application. Since analysis and optimization are considered key components of the engineering design process

(Gattie & Wicklein, 2007), it helps students better understand the application of the engineering design process as performed by real-world engineers.

Engineering Communication

This aspect involves such topics as developing presentations and visual representations such as CAD (Computer-Aided Design) drawings (Childress & Rhodes, 2008). Asunda and Hill (2007) expressed the importance of being able to communicate results and Wicklein (2006) explained that a course in CAD would be a useful addition to the technology education curriculum. In addition to these aspects, Childress and Rhodes (2008) explained that engineering communication should involve the keeping of a technical or engineering notebook. The importance of an engineering notebook as a data collection tool as well as a tool for student reflection and understanding of the engineering design process was described by Kelley (2011). While students completed an engineering notebook throughout the course of the unit, the use of CAD drawings and presentations fall outside the time constraints of this particular unit of instruction and thus were not be used. Denson and Lammi (2014) explained that there should be some mode of assessment as a critical feature. Within that category, many of the six authors recommended that students be able to communicate their results and this could be a source of evaluation for the students. This also is a practice performed by engineers and is thus a practical application of evaluation.

Engineering Science

Materials design, tool usage, and the application of power and energy concepts are some of the areas which fall within engineering science (Childress & Rhodes, 2008). This study focused on the application of power and energy as students will have to understand the law of conservation of energy as well as the concepts of potential and kinetic energy. Wicklein et al.

(2009), sought to determine essential concepts of engineering design curriculum, finding that "according to the results of the Delphi study, the following survey items for research question three received the highest mean scores: Newton's laws: forces, reactions, velocity & acceleration (M = 5.42), Types of energy (M = 5.25), and Summation of forces/force equilibrium (M = 5.00)" (p. 71). The activity performed by students will address each of these areas in both instruction and application through the use of ballistic trajectories. Additionally, this activity emulated an exercise already conducted by Merrill et al. (2008) in their study on how to deliver core engineering concepts to high school students. Sequencing of concepts was another important concept that Denson and Lammi (2014) described as ensuring that the problems were age-appropriate and structured properly based on student experience. The mathematic and scientific concepts described are not only aligned with standards at the high school level, but are simplified to an algebraic level which allowed students that are primarily freshmen the ability to complete the task based on the mathematic skills they already possess.

Addressing the Core Concepts

As aforementioned, this study applied many of the core concepts identified by Childress and Rhodes (2008) as well as those described by Denson and Lammi (2014). While it is not possible nor recommended to cover all the concepts of engineering design in a single unit of instruction, this study addressed the top five areas as identified by Childress and Rhodes (2008). These areas are also considered important by Asunda and Hill (2007), Asunda (2012), and Gattie and Wicklein (2007). Additionally, each of the aspects of this study address specific standards as set forth by the ITEA (2007) in their *Standards for Technological Literacy* which allows this study to be readily implemented into a technology education classroom while providing minimal conflict with required standards. Finally, each area falls within the priorities set by Denson and Lammi (2014).

Engineering Design Evaluation

Kelley and Wicklein (2009b) clarified the definition of evaluation as placing value on student work. In the second part of their three-part study, they enumerated the areas in which educators evaluate engineering design projects completed by students. Of these, they found that researching the problem, predictive analysis using mathematics and science, and documentation using an engineering notebook were critical practices which can be used to determine student understanding. Eide et al. (2002) elucidated the importance of research as it assists in more clearly defining the problem. Additionally, Kelley (2010a) depicted the importance of research in its ability for students to tie the problem to themselves and create a personal connection. Smith and Wicklein (2007) portrayed the importance of predictive analysis as critical and necessary for creating knowledge, further integrating engineering and technology, and creating a link between technology education and other subjects such as mathematics and science. Finally, Kelley (2011) presented the concept of using an engineering notebook as a means to comprehensively understand the student's thought process and learning throughout the engineering design process. This study assessed these areas through the use of the engineering design rubric created by Asunda and Hill (2007) and the incorporation of a student engineering design notebook as well as a rubric to assess it designed by Kelley (2014). This study sought to better understand the implementation of the aforementioned concepts as well as to develop curriculum which properly implements all the aspects of engineering design. The model adopted by this study and which is uniquely suited to this purpose is action research.

Action Research in Education

Maksimovic (2010) asserted that in action research, educators are not simply objects or passive recipients of research, but active participants. Therefore, its roots can be traced to classical pedagogy dating back to John Dewey's notion of controlled inquiry, where rational thought and action are interspersed in the learning process (Baskerville & Meyers, 2004). Brydon-Miller, Greenwood, and Maguire (2003) and Brown (2012) asserted that Dewey's description of practice and inquiry mutually informing one another coincides with how action research is performed. Dewey (1910) described thought as a reflective process that is difficult and sometimes painful, but yields ideas that are solutions to problems experienced by the thinker. This concept of reflective thinking for problem-solving can be considered the basis of action research (Stringer, 2014). However, action research also has its roots in social action. While Dewey focused on reflection from an educational perspective, the concept of social research as an element of change became popular in Britain and eventually in the United States, focusing on various social and organizational issues (Noffke, 2009). Yet, these various aspects were not drawn into a more concise definition until Kurt Lewin coined the term action research to denote research within a natural setting designed to effect change within that setting (Ferrance, 2000).

Lewin was not the only individual working towards refining the concept of action research. In the United Kingdom, researchers attempted to define teaching as a form of research in and of itself, further grounding action research in educational practice (Noffke, 2009). These and like-minded researchers eventually founded the journal Educational Action Research in 1993.As action research progressed, others added their voice to the body of literature focused on action research. Kemmis and McTaggart (1988) helped develop a model for the action research cycles, based on Lewin's concepts of planning, acting, and reflecting. Noffke (2009) explained that a number of other works espousing the virtue of action research in education, as well as writings on how to conduct action research, saw renewed interest. Cochran-Smith and Lytle (1999) described a renewal in interest in teacher research and practitioner inquiry as the teacher research movement. While this movement toward action research began over 100 years ago, it is still considered by many institutions and researchers to be a relatively newer means of conducting research and, thus, has met with some resistance from institutional review boards. Academics have also expressed concern over the conflict between formal knowledge and practical knowledge (Herr & Anderson, 2005). Critiques such as those leveled by Gibson (1985) asserted that action research lacks the validity of traditional, institutional research because of its lack of self-critique. Kelley, Davey, and Haigh (2000) further explained that these criticisms of validity are, in essence, a fear of the loss of control over the research environment. Additionally, they described that many traditionalists will support this claim through the argument that they "do science while action researchers merely tell stories" (p. 3). The nature of self-reflection and focus on the researcher as the researched has also proven contentious with academics (Herr & Anderson, 2005). Kelley et al. (2000) explained that critics cite this obvious bias as lacking objectivity, as if there were a neutral point where subjectivity in research ends and true research is conducted. However, these criticisms have been rebutted by those such as Zuber-Skerritt (1992) who asserted that a truly neutral point of research cannot exist, but is rather an illusion and that there is no interpretation-free reality. Carr and Kemmis (1986) explained that the fear of loss of control comes from entrenched interests of academics in traditional research settings and that if such claims were true, then much of educational research, especially critical research would be void. Further, Mertler (2014) explained that action research is not designed to be generalized, but to provide localized solutions to the researcher. Therefore, these arguments do not stand to scrutiny and thus have not halted the progression of action research.

Planning an Action Research Study

Due to its unique and diverse roots, action research encompasses a variety of strategies and frameworks. Before establishing a framework for a study, an area of research interest should be chosen, as this will dictate the type of action research conducted. For example, if a researcher were interested in changing a government policy related to a social issue, they may choose critical action research because of its focus on critiquing the current issue and providing a proposed solution. In my proposed study, the focus is on educational practice, and therefore, educational action research will be performed.

In educational action research participants focus on examining their own educational practice rather than a specific social issue or problem. Educational action research, hereafter referred to as action research, can be performed by an individual researcher, collaboratively with other researchers or teachers, or even in a system-wide design with large numbers of researchers (Ferrance, 2000). Additionally, there are a number of quantitative, qualitative, and mixed-method designs for collecting data in action research (Mertler, 2014). Therefore, when performing educational action research, it is important to identify the positionality of the researcher and data collection design. Herr and Anderson (2015) explained that positionality in action research refers to the status of the researcher in relation to the group in which the action research is taking place. They described a continuum that progresses from insider status to outsider status. Insiders are those who can be identified as part of the group with whom the research is being conducted, while outsiders may not be part of the group but seek collaboration with group members. They further described teachers as insiders in action research as they study their own practice and attempt to effect change within their setting. Mertler (2008) further described this continuum as one that is based on observation versus participation. On one end, the researcher passively observes while those being studied may not even know they are being studied. On the other end, the researcher is a full participant in the community or group while still collecting data. Mertler (2008) further suggested that understanding one's role in the or positionality directly impacts how and what types of data are collected. The study placed me as an insider within my own practice as Herr and Anderson (2015) described. Additionally, I was a full participant as I designing, implementing, and reflecting upon the research myself. Johnson and Christensen (2014) described this positionality as individual action research, which is planned, designed, and conducted by a single teacher in their classroom environment.

Why action research?

Within technology education, there is a lack of educational resources and training for teachers to implement the engineering design process, and more specifically, design optimization into their classroom (Kelley & Wicklein, 2009a) These deficiencies have also made it difficult to properly implement these concepts into my robotics classroom. The purpose of this study was to improve my practice by designing, implementing, and reflecting upon educational resources and training related to engineering design and design optimization. Therefore, the action research methodology is appropriate for this study for the following reasons. Mertler (2014) explained that in order to improve education, teachers must be willing to reflect upon and improve their practices. This desire for improvement has led more teachers to conduct action research through a variety of means, such as professional development, certificates, and coursework. Rearick and Feldman (1999) asserted that this proliferation of action research in education is due to its success in impacting classrooms and thus, is appropriate for my classroom. While action research is appropriate for my classroom, it also satisfies the need to generate a change in student learning and outcomes through the improvement of curriculum and teaching methods, which is a result of the reflection which occurs in each of the cycles (Koshy, 2005). However, McKernan (1988) explained that not only can a teacher's practice be improved through action research, but that teachers can develop new curriculum and interventions which could ultimately be shared with other technology education teachers. Therefore, action research's success in positively impacting the classroom through the improvement and development of new resources and strategies aligns well with the purpose of this study.

Kolb's Learning Theory

Kolb (1984) explained that learning or knowledge is generated through the interaction of theory and experience. He described this theory on learning as experiential learning. While his most well-known work was published in 1984, Kolb first developed the learning styles inventory during his research in the 1960s and uses this tool as the basis for constructing his theory of experiential learning (Miettinen, 2000). Tamaoka (1985) described these learning styles as similar to cognitive styles but with a focus on individual attitudes towards learning. He explained that cognitive styles refer primarily to the way in which a learner prefers to acquire information from their environment while learning styles focus more on the learning situation itself and can thus be more specific when discussing learning environments which are conducive to student reception and assimilation. Cherry (n.d.) explained that Kolb's learning styles is one of the most widely used and popular learning inventories developed to date. In his learning styles inventory, Kolb described four components; the converger, the diverger, the assimilator, and the accommodator (Cherry, n.d.). Tamaoka (1985) explained that these styles were used in conjunction with specific learner experiences to create a grid which specifies each type of learner as seen in Figure 2.2.

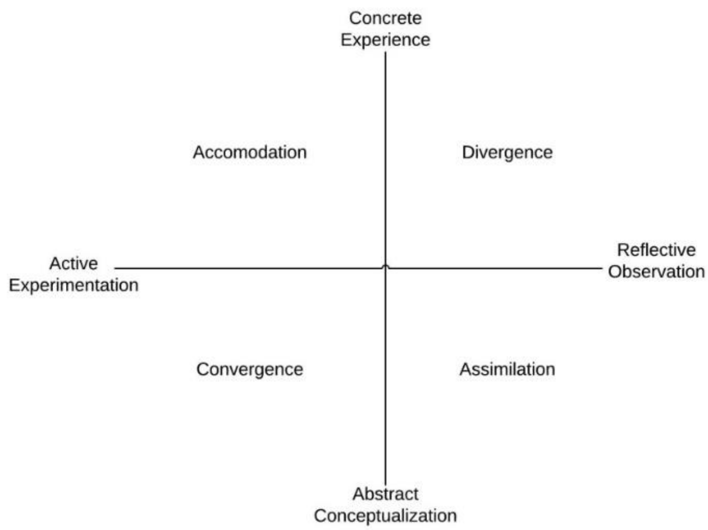

Figure 2.2. Kolb's learning cycle and styles described by Tamaoka (1985).

Tamaoka (1985) explained that this grid emphasizes specific strengths of each of the styles. For example, those with accommodating and divergent styles would prefer concrete experience with learning. This division eventually leads to two areas of strength for each style. For example, assimilating styles would be strong in the reflective observation and abstract conceptualization while accommodation styles would prefer concrete experience and active experimentation. Based on these strengths, Kolb designed an inventory of questions which help individuals determine which learning style they prefer (Tamaoka, 1985). Koob and Funk (2002) described each of these styles. The diverger is more imaginative and interacts well with people while convergers are more logical and prefer tangible things over people. Assimilators focus on inductive reasoning and combining information into logical thoughts and are prone, like convergers, to prefer things over people. Accomodators are considered "risk takers and problem solvers" (p. 295) and are willing to try new experiences and interact with people. Since the creation of these learning styles, there has been substantial research performed in the areas of psychology, management, education, and a number of other diverse fields in which researchers have found it useful in developing interventions amongst its many other uses (Koob & Funk, 2002).

Experiential Learning

As these learning styles were being tested and refined, Kolb designed a theory for learning that used these styles as its framework. This learning theory is called experiential learning. The naming of this theory is designed to serve two purposes. The first is to tie the theory to the work of Dewey, Lewin, and Piaget. The second is to emphasize the importance of experience in the educational process (Kolb, 1984). Kolb (1984) addressed how learning styles were linked to Dewey, Lewin, and Piaget. He made the argument that Dewey's model of learning incorporates "experience and concepts, observations and actions" (p. 22). Ord (2012) designated this process transactional due to the learner's interaction with their environment. He also echoed Kolb's argument that Dewey's learning theory is the underpinning for experiential learning because of its roots in environmental interaction and constructivism. Kolb (1984) assimilated Dewey's transactional learning with that of Lewin. Both describe learning as a feedback process where the individuals are pushed to further action through the initial concrete experience. Torkington (1996) further explained that Lewin's concept of learning is iterative. Additionally, its occurrence is due to an interaction between theory and practice which strengthens the concept that knowledge is constructed through a transactional process with one's environment. Ord (2012) explained that this process is described by Kolb as dialectic, or that learners experience opposing forces or conflicts in the process and are pushed by these forces into the various stages of the learning cycle. Piaget was referenced by Kolb (1984) as defining the individual steps through his model for adult learning. He explained that experience, concept, reflection, and action are the continuum which individuals follow as they proceed in adult thought. Torkington (1996) explained that the relationship between experiential learning and Piaget falls not only within the adult learning continuum but also through the belief held by Piaget that intelligence is not innate, but rather it is experiential and is shaped by the learner's interaction with their environment as they proceed throughout their lifetime. Kamii and Ewing (2012) explained that this theory is rooted in constructivism, or the idea that individuals construct or build knowledge within them. They asserted that Piaget played a central role in defining and spreading the theory of constructivism which has become a popular view for designing educational experiences in recent years.

Constructivism and Education

Educational theorists have attempted to determine how individuals gain knowledge or learn throughout the course of time. There are a variety of theories which explain the nature of acquiring knowledge and learning. One such approach is constructivism. Larochelle, Bednarz, and Garrison (1998) explained that constructivism has allowed us to look at a new way of developing the concept of knowledge. They explained that constructivism assumes that knowledge is created or constructed by the individual acquiring it, and this view has led to a surge in educators attempting to include activities and educational schema which include more learner-centric activities. They also explained, while some views of the more purist radical constructivism have not been adopted by educators, the viewpoint that learners are situated contextually in the learning environment and that this situational placement has an impact on what and how the learner appropriates knowledge has had an impact in education. Jones and Brader-Araje (2002) described the changes in education towards constructivism as a result of the failed implementation of behaviorism. They explained that the adoption of constructivism took into account the use of prior knowledge and the understanding that student knowledge varies based on their environment. They explained that understanding the concept of prior knowledge and the difficulty it presents when trying to change or introduce new ideas has led teachers to attempt to understand student preconceptions first and then introduce concepts in concrete examples. This helps the students better assimilate the preconceptions with the new information. As Kolb (1984) described it, this is the first stage of the learning cycle, known as concrete experience. Further, constructivism helped teachers understand the importance of building knowledge in a logical process while being sensitive to student knowledge which supported and enhanced the learning environment (Jones & Brader-Araje, 2002). The impact of constructivism on student learning is best summarized as

> Constructivism offers teachers instructional approaches that are congruent with current research on learning. By viewing learning as an active process, taking students prior knowledge into consideration, building on preconceptions, and eliciting cognitive conflict, teachers can design instruction that goes beyond rote learning to meaningful learning that is more likely to lead to deeper, longer lasting understandings. (Jones & Brader-Araje, 2002, p. 4)

This definition closely mirrors the concept of the learning cycles as established by Kolb (Kamii & Ewing, 2012).

Kolb's Learning Cycle

There is an interdependence between Kolb's learning cycle and the learning styles inventory he developed. Based on his understanding of Lewin, Piaget, and Dewey's works, Kolb determined that experiential learning is a cyclical process (Kolb, 1984). He described this process as being one of struggle between different ways of viewing the world. Kolb (1984) explained that Lewin's conflict was the abstract versus concrete experience. However, Piaget's conflict occurred between assimilation of new ideas into existing knowledge structures and accommodation of structures within the physical world. Further, he described Dewey's conflict as the impulse that forces new ideas and the direction of this force through reason. Therefore, Kolb (1984) argued, these conflicts require the learner to be able to operate in four defined spaces: concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE). By moving through each of these spaces during the learning process, the individual alleviates the conflict between the aforementioned constructs and is able to better construct new knowledge. Tamaoka (1985) explained that most learners, however, tend to gravitate towards a single style as described by Kolb's Learning Styles Inventory. Therefore, the primary benefit of performing the learning cycle as defined by Kolb was the ability to operate in each of the areas and thus be able to " circulate the learning process" (p. 15) effectively. In other words, as learners are conditioned to use such a cycle, they are able to learn more efficiently and holistically the concept being taught. Torkington (1996) echoed this conclusion by asserting that Kolb did not deem one learning style as superior to another but understood that each learner would have strengths and weaknesses in the various styles. Therefore, the ideal learner would "have a combination of all four learning styles" (p. 14). Additionally, she explained that this theory is firmly based in reality due to the uniqueness of each student. She explained that the teaching of this cycle is important because we learn the way we are taught, and thus teaching how to learn correctly is of the utmost importance. While Torkington (1996) supported the incorporation of Kolb's theory in educational practice, it is important to understand how each of the cycles is defined and what activities address the learning styles represented.

Montgomery and Groat (1998) further described each cycle in terms of how it addressed a question that students could ask about the concept being learned. This question can also serve as an understanding of how each cycle addresses a specific concern.

Table 2.5

Kolb's Learning Cycle Phases and their Properties (*Kolb, 1984, p. 31.)*

Phase	Definition	Question
Concrete Experience (CE)	Learners "involve themselves fully, openly, and without bias in new experience"	Why?
Reflective Observation (RO)	Learners "reflect on and observe their experiences from many perspectives"	What?
Abstract Conceptualization (AC)	Learners "create concepts that integrate their observations into logically sound theories"	How?
Active Experimentation (AE)	Learners "must use theories to solve problems"	What if ?

While understanding each of the phases and their definitions is important, selecting activities that fit within this theoretical model could prove challenging. Therefore, Svinicki and Dixon (1987) provided a number of activities which model each of the learning styles and phases.

Table 2.6

Activities for Kolb's Learning Cycle as Described by Svinicki and Dixon (1987)

Phase	Activities
Concrete Experience (CE)	Laboratories, Observations, Primary Text Reading, Simulations/Games, Field Work, Trigger Films, Readings, Problem Sets, Examples
Reflective Observation (RO)	Logs, Journals, Discussion, Brainstorming, Thought Questions, Rhetorical Questions
Abstract Conceptualization (AC)	Lectures, Papers, Model Building, Projects, Analogies
Active Experimentation (AE)	Simulations, Case Study, Laboratory, Field Work, Projects, Homework

Kolb's Learning Cycle in Practice

Koob and Funk (2002) explained that Kolb's Learning Styles and Cycle theory have been applied in a variety of fields since its inception in 1984. Some of these fields are computer science education and statistics, arts and science, and vocational training. They explained that these studies found practical applications of Kolb's theory in "heralding diversity, identifying useful interventions, and promoting an atmosphere of greater appreciation for differences among learners" (p. 296). Miettinen (2000) concurred with their assessment of Kolb's Learning Cycles as being "[regarded] as classical and as a foundation for experiential learning" (p. 55). Additionally, he explained that "it is used routinely as a source for literature in the field" (p. 55). Ord (2012) concurred with Miettinen (2000) and Koob and Funk (2002) by his observation that "it is hardly surprising that experiential learning as a simplistic cycle has considerable currency in the field of youth work and is incorporated into a large number of curriculum documents" (p. 57). While these assertions are more general, there are two studies which corroborate these claims and help solidify the validity of Kolb's Learning Cycle theory.

Jaksic's PLCS and Kolb's learning cycles. The first of the aforementioned studies was Jaksic's (2010) research on the implementation of Kolb's learning cycle to teach the use of PLCs. This course, a part of the engineering courses offered at Colorado State University, dealt with teaching students to work with programmable logic controllers (PLCs). The study consisted of implementing four instances of Kolb's learning cycle as they progressed through the curriculum. Each cycle covered a specific topic and contained a content-based quiz. Additionally, the students took a comprehensive test at the end of the units. At the completion of the data gathering, Jaksic (2010) had the students complete a survey regarding Kolb's learning cycle and their learning experience. The result of this strategy was an increase in quiz and test scores as well as students expressing a deeper knowledge and appreciation of Kolb’s learning cycle. Jaksic (2010) summarized these results by stating "it is expected that the long-lasting effects of the Kolb's cycle implementation will result in positive changes in students' and later engineers' approaches to learning" (p. 10). This study presented a gain in student achievement in teaching engineering concepts, which is echoed by the second study of interest performed by Konak, Clark, and Nasereddin (2014).

Kolb's cycle and VCLs. In their study, Konak et al. (2014) implemented hands-on teaching skills with Kolb's learning cycle to improve student performance in a computer programming and networking course. Their research implemented an experimental setup with both a control and treatment group. While the control group was taught as normal, the treatment group received instruction with activities as prescribed by Kolb’s learning cycle. At the conclusion of the unit, students were provided a survey instrument asking about the learning experience. Konak et al. (2014) found that the treatment group had higher levels of interaction with peers, interest in the subject, engagement with the materials, and competency in understanding the concepts based on their responses. Each of these findings was statistically significant. Additionally, the researchers administered a quiz in which the treatment group outscored the control group to a statistically significant level. Based on the performance of students in both of these subjects, which are closely related to the field in which I will be researching, it appears that using Kolb's learning cycles should enhance my students' learning and thus is a reasonable application of the theory.

Kolb’s Learning Cycle and Other Educational Theories

Kolb’s learning styles and learning cycle are not the only educational theory which can be applied in the teaching of the engineering design process. The most prominent educational theory applied in similar circumstances is Project-Based Learning (PBL) (Householder & Hailey, 2012). Savery (2006) described PBL as "an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (p. 9). Strobel and van Barneveld (2009) explained that this theory of instruction was developed to enhance learning in various healthcare industries and since has been a staple in many educational settings. Barrows (2002) described PBL as having four primary characteristics which are (a) the use of ill-structured problems, (b) a student-centered approach, (c) teachers acting as facilitators or tutors, and (d) authenticity of the problem through real-world examples. Householder and Hailey (2012) described the positive impacts that PBL can have on student learning as; increasing student performance and motivation, improving depth of understanding of concepts, and enhancing long-term retention. However, Strobel and van Barneveld (2009) explained that there is a heated debate amongst some scholars as to the effectiveness of this method. While PBL provides a number of compelling reasons for its implementation, there are some drawbacks in relation to the structure and timing of this study which makes it incompatible. Mills and Treagust (2003) explained that project-based learning activities necessarily take an extensive amount of time to complete. They explained that often, such projects can last an entire semester. Since multiple cycles must be completed for this action research study in a set amount of time, this style of teaching would not be compatible with the time frame of a PBL activity. Additionally, PBL is applied to ill-structured problems where students are allowed to select the problem and guide their own learning (Barrows, 2002). However, part of the desire of this study is to teach specific mathematic and scientific concepts. Mills and Treagust (2003) admit that PBL can be difficult to align with specific standards because of the freedom that students have in the exploration of their topic and solution. Denson and Lammi (2014) included alignment with curricular standards as one of the key aspects of an engineering design activity. Additionally, students at this level lack much of the requisite skills and knowledge to identify their own topics and learn the required mathematic and scientific concepts. Yet Householder and Hailey (2012) posited that PBL works best with ill-structured problems. Hynes et al. (2011) and Eisenkraft (2011) explained that novice problem solvers should begin with well-structured problems and move to ill-structured as their knowledge and ability progress. Since was the first introduction of the problem-solving process to these students, they will need to begin with a more structured problem. Finally, unlike Kolb, there is neither mention nor addressing of individual learning styles in PBL. Bostrom, Olfman, and Sein (1990) explained that learning styles are an important part of educational psychology and can directly affect student learning and outcomes. This assertion is supported by educational psychologists such as Entwistle (2013) as well as engineering educators like Felder and Silverman (1988). Therefore, while PBL is a teaching style which has a number of strong points, it is not a proper fit for this study.

Arguments Against Kolb's Learning Cycle

While Kolb's learning cycles and the learning styles he developed have been widely accepted and integrated into educational instruction, there are some notable critics of Kolb's work. Koob and Funk (2002) asserted that the primary critique of Kolb's Learning Styles and Cycle is that it lacks predictive validity. However, Kayes (2002) explained that the Learning Styles Inventory (LSI) and learning cycle were not developed as a predictive tool, but rather for individuals to better understand their own preferences in learning and as descriptive tool to help them better identify learning strategies which may work best for them. Koob and Funk (2002) noted that, while the predictive capabilities of the LSI were lacking, that the learning cycle model and learning styles have been used numerous times in various studies to develop interventions and curriculum which have been shown to enhance student learning and understanding of concepts. Another concern regarding Kolb’s learning cycle and LSI is the perception of some theoretical problems. Hopkins (1993) summarized some of these concerns as; the rejection of scientific measures and outcomes, a lack of objective qualities of learning experiences, and inadequate explanation of interdependence and variability in learning in relation to his learning styles. However, Kolb (2005) in his latest version of the Learning Styles Inventory addressed these concerns. In relation to the construction of knowledge, Kolb (2005) stated that “learning is best conceived as a process, not in terms of outcomes. To improve learning in higher education, the primary focus should be on engaging students in a process that best enhances their learning —a process that includes feedback on the effectiveness of their learning efforts” (p. 2). Kolb’s assertion that learning is a process and it should be focused on student engagement does reject empirical methods. However, he does include the possibility for feedback which could come through various, objective means. This, Kayes (2002) asserted, is fundamental to pragmatism and to Kolb’s theory, that practical knowledge generation through experience is more important than objective measures of that knowledge. To explain the interrelatedness of the various learning styles, Kolb (2005) explained:

> Experiential learning is a process of constructing knowledge that involves a creative tension among the four learning modes that is responsive to contextual demands. This process is portrayed as an idealized learning cycle or spiral where the learner “touches all the bases”—experiencing, reflecting, thinking, and acting-in a recursive process that is responsive to the learning situation and what is being learned. (p. 2)

While this explains the interdependence of the learning styles within the cycle, it does not include reasoning for the variability in learning styles nor the shift from one style to the other. Kolb (2005) later explained that the variability in learning styles can come from a variety of areas, but that they tend to be focused around an individual's personality type, educational specialization, professional career, current jobs, and adaptive competencies. He includes a detailed explanation as to how each of these areas can impact and change a person's learning styles and preferences.

A third, and final, concern is that the learning cycle and learning styles do not take into account gender and ethnicity. This concern is specifically addressed to the LSI as Koob and Funk (2002) provided an example where it struggled with prediction of learning styles of Asian students in a study. Although, once the cultural implications were taken into consideration, it was more capable in predicting learning styles. Joy and Kolb (2009) performed a study with over 500 participants from various countries which Kolb used to identify various adjustments to the learning styles which can be made based on the cultural differences experienced. Overall there are some concerns addressed by critics of Kolb's learning cycle, much of which is directed at the LSI. However, as Kolb (2005) explained, there are over fifteen hundred published studies implementing his learning styles and cycle. Based on those studies, Hickcox (1991) found 78% full or partial support for the theory while Iliff (1994) found 88% full or partial support of the theory. While some of the concerns expressed are valid, the overwhelming support in the literature for the use of Kolb's learning cycles in engineering education as well as its close ties to Lewin and action research situate it as the best educational theory for this study.

CHAPTER 3 METHOD

Purpose

The National Center for Engineering and Technology Education (NCETE) was founded as a part of the National Science Foundation in 2003 to address the integration of engineering and STEM (Science, Technology, Engineering, and Mathematics) based concepts into education (Hailey, Erekson, Becker, & Thomas, 2005). As a part of their mission, the NCETE set the goal of introducing the engineering design process into technology classrooms since many technology teachers are now being pushed to incorporate STEM principles in their teaching. However, Hailey et al. (2005) asserted that there is a distinct difference between the engineering design process and what the International Technology Educators Association (ITEA) set as standards for design. While technology educators have a design process that is similar to the engineering design process, it lacks the steps of analysis and optimization, which engineers use determine the best (or optimum) solution and eliminate inferior solutions. The application of math and science principles to analyze and optimize generates a more robust design than the concept of trial and error which is advocated by the ITEA standard.

The focus of this study was on the engineering design process and specifically analysis and optimization as its absence has been observed by Wicklein, Smith, and Kim (2009) in their research as well as in my own classroom practice. This thought is further supported through informal discussion with other technology educators. As such, the purpose of this action research study was to enhance my practice through the development of a unit of instruction which teaches high school students the application of these principles.

Research Questions

The students completed a unit of content that involved a challenge that required using the engineering design process, as well as accompanying mathematic and scientific concepts. Through each cycle my instruction improved based on data analysis and my reflection as a researcher. The overarching question answered at the completion of this study was

> In what ways can I improve my practice of teaching the engineering design process through the application of the action research methodology?

To better understand the specific components that led to the improvement of my practice and to ascertain a clearer understanding of the answer to this primary question, a set of questions were answered at the end of each cycle:

1. To what degree do students understand the elements of the engineering design process, ballistic trajectories, and the laws of conservation of energy?
2. How effective were instructional strategies in enhancing student understanding of relevant mathematical and scientific concepts?
3. How do students explain the practical application of course content to their lives?

Research Design

The study used an action research design that focused on the researcher as the target of interest. Unlike other qualitative and quantitative methods, action research seeks to better understand practice and implement change through the use of reflective practice (Johnson & Christensen, 2014). In action research a cycle consisting of four stages is repeated multiple times. Each stage has a unique purpose in the cycle. The first stage is planning, which includes identifying the problem, researching information related to the problem, and then developing a plan of implementation (State of New South Wales, 2010). The next stage is to take action by implementing the plan that was developed. Data is collected for the next stage, which is developing (Mertler, 2014). In the developing stage, the researcher analyzes the data collected and organizes findings (State of New South Wales, 2010). Once findings are known, the final stage of reflecting (Mertler, 2014) can begin. In this stage findings from the observation stage are evaluated, as well as reflection on the entire cycle (State of New South Wales, 2010). This reflection produces changes that need to be implemented in the next cycle where the four stages are repeated. The integration of the changes produced from the reflection stage points to the importance of performing multiple cycles. Much like the business concept of continuous quality improvement, the repetition of cycles refines and improves practice. (Johnson & Christensen, 2014). This process can be seen in Figure 3.1.

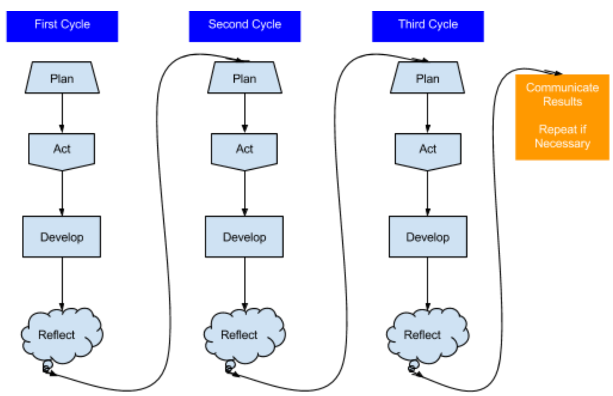

Figure 3.1. Explanation of the action research methodology through cycles and phases as redrawn from Reil (2010)

Defining Action Research

Action research is a design that developed out of the unique need of qualitative researchers to improve practice and generate change in organizations and society (Mills, 2014). Kurt Lewin is considered the father of action research (Johnson & Christensen, 2014), and since its inception, a variety of methods and explanations have been developed. McKernan (2013) described action research as a “rigorous, systematic inquiry through scientific procedures; [and that] participants have critical-reflective ownership of the process and the results" (p. 17). This definition adequately describes action research as a method but does not address education specifically. Schmuck (2006) best described educational action research as "planned, continuous, and systematic procedures for learning about your professional practices and for trying out alternative practices to improve outcomes" (p. 29).

The Action Research Framework

Action research can be conducted by an individual, collaboratively with others, and even in a system-wide design with large numbers of researchers. Additionally there are a number of quantitative, qualitative, and mixed-method strategies for collecting data in action research. Therefore, when performing educational action research, it is important to identify scope and data collection procedures. Scope refers to the number of individuals conducting the research, while data collection refers to how and what types of data are being obtained. For this study, I am the only individual who teaches robotics. Students in my class provided data in each cycle, but were not included as collaborators. Therefore, the scope of this study was individual action research. Johnson and Christensen (2014) explained that individual action research is planned, designed, and conducted by a single teacher in their classroom.

Once the scope of the study is determined, the method of data collection is selected. While qualitative and quantitative methods can be used, Mertler (2014) recommended a mixed-method approach that allows both quantitative and qualitative data collection. There are a variety of ways in which the qualitative and quantitative data for a mixed-method design can be analyzed. Creswell (2005) explained that one of the most popular and widely used is triangulation. Gorard and Taylor (2004) stated that this popularity stems from the synthesis of multiple data points to obtain a more practical product, which is a rising expectation of educational research. They provided two examples of the implementation of triangulation. The first, and most accepted, is the idea of a surveyor. A surveyor uses two predetermined points to understand information such as angle, location, etc… of a third point in the triangle. Similarly, researchers use two types of data to gather information about a concept that is the third point of the triangle (see Figure 3.2).

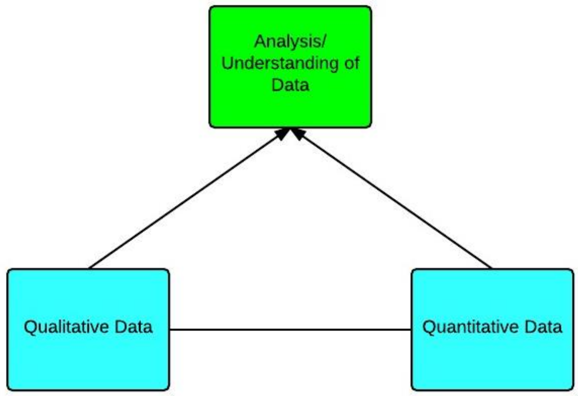

Figure 3.2: Triangulation as described by Gorard and Taylor (2004).

A less common approach to triangulation is treating the analyzed theme as the center of a triangle and to use three data points to encapsulate the idea or information about it. This study employed the first example due to its simplicity and acceptance by the research community. The collection of data for triangulation can occur at different times, with different paradigm emphasis, and different incorporation of analysis (Terrell, 2012). Although there are various strategies that can be implemented based on these criteria, Terrell (2012) described the strategy that was employed in this study as a concurrent triangulation strategy. Creswell (2005) and Terrell (2012) explained that this strategy collects and analyzes both quantitative and qualitative data at the same time without emphasis on either data type. Interpreting the data occurs at the conclusion of collection. The variety of strategies as described by Creswell (2005) can be seen in Figure 3.3.

The advantage of concurrent triangulation is that it utilizes the strengths of both qualitative and quantitative research while also mitigating some of the non-overlapping weaknesses (Creswell, 2005). This method is used when attempting “to obtain different but complementary data on the same topic” (Morse, 1991, p. 122) which helps us to better understand the problem. Creswell (2005) and Terrell (2012) explained that there are multiple benefits to using concurrent triangulation; it is widely used by researchers, it is time efficient, and data can be analyzed simultaneously. This scope and design allowed the study to address the questions posed and fulfill the specified purpose.

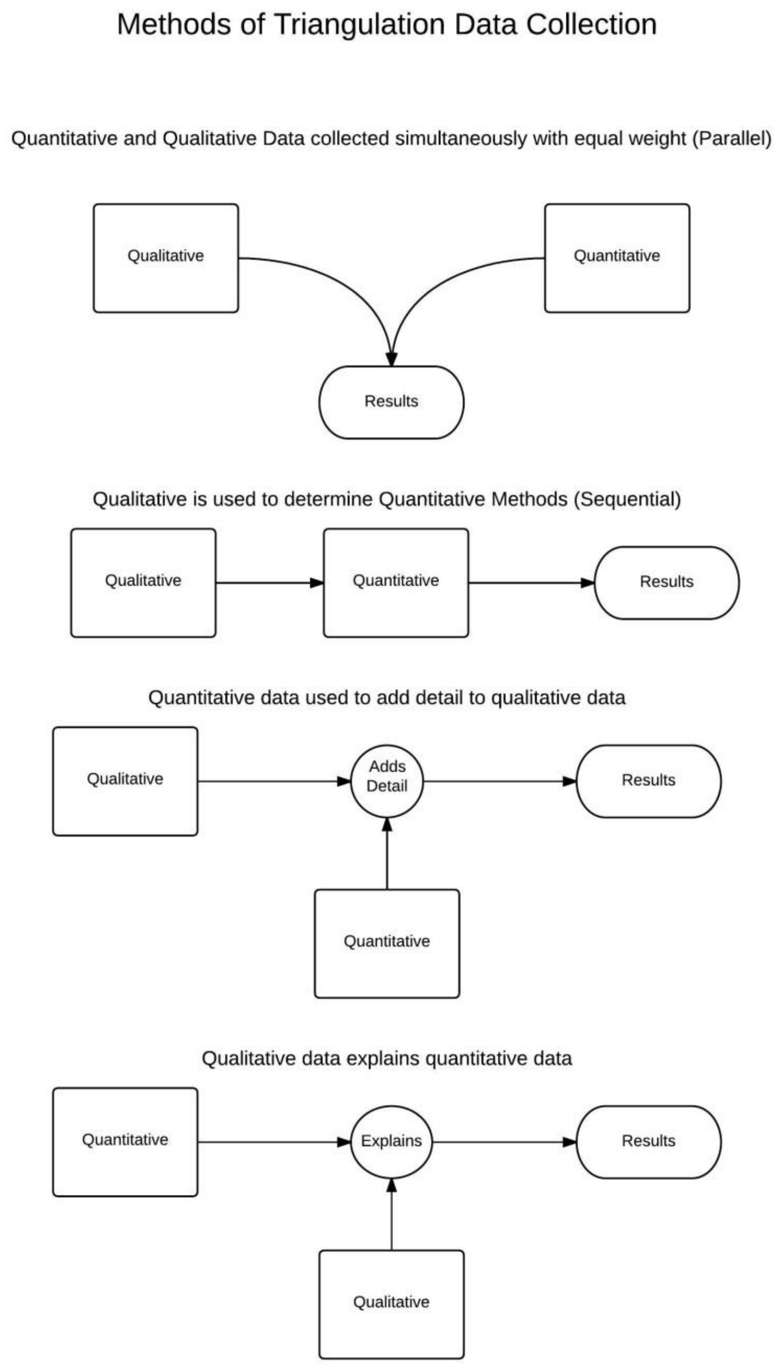

Figure 3.3: Different methods of triangulated data collection as explained by Creswell (2005).

Importance of Action Research

Educational action research is important for three reasons. First, Mertler (2014) explained that in order to improve education, teachers must be willing to reflect on and improve their practice. Because of this need, more teachers are conducting action research through a variety of means such as professional development, certification, and coursework. Emphasis on action research in education has been growing rapidly in recent years and situates itself as a method that works well in the classroom (Rearick & Feldman, 1999). Second, one of the primary purposes of educational action research is to generate a change in student learning and outcomes (Koshy, 2005). Finally, educational action research can be used to develop new curriculum and remedial interventions that can improve teaching practice (McKernan, 1988). These reasons aligned directly with the purpose of my study and addressed the overall import of improving educational experience for students.

Advantages of Action Research

Because educational action research can be performed by teachers in their classrooms, the researcher can be an insider. This allows greater access to students and removes them from the conflict that would typically occur in experimental research. Action Research also allows the teacher-researcher to reflect on and modify their practice as the research is performed, which allows for greater flexibility in design (Koshy, 2005). Additionally, the objective of action research is to enact change in the classroom, as well as generate useful curriculum, knowledge, and instruction that can be shared, implemented, and refined (Koshy, 2005). Finally, action research allows for a mix of quantitative and qualitative data collection measures that can more accurately represent the educational environment and lead to a more robust change (Mills, 2014).

Validity and Reliability

Ensuring the quality, rigor, and validity of action research is a concern due to its mixed application of qualitative and quantitative methods. This study fulfilled all the concerns of validity and reliability as set forth by Mills (2014), Stringer (2007), and Melrose (2001). Mills (2014) explained that action research falls under a different criteria than other research designs, known as rigor. Stringer (2007) divided rigor into four areas which he defined

- Credibility—the plausibility and integrity of the study
- Transferability—the possibility of applying the outcomes of the study to other contexts
- Dependability—research procedures that are clearly defined and place
- Confirmability—evidence that the procedures described actually took place (p. 114)

Stringer (2007) asserted that rigor in action research is primarily concerned with credibility. To ensure the credibility of this study, each component of rigor was addressed (see. Table 2.7).

Table 2.7

Components of Credibility and their Application (Stringer, 2007)

Credibility Component	Definition	Application
Prolonged engagement	Significant time committed to explore and learn	Study will take place over two semesters and multiple weeks
Persistent observation	Researcher actively involved in observing and documenting	Teacher observation journal kept throughout all cycles
Triangulation	Use of multiple data sources	Total of 3 types of data sources with a total of 6 individual sources
Member checking	Allow individuals to verify content and express thoughts	Students provide feedback through semi-structured interviews
Diverse case analysis	Inclusion of all stakeholders in research	All classes of robotics students that I teach will be included
Referential adequacy	Analysis drawn from stakeholders, should not follow predefined schema	Analysis occurs through reduction and theme analysis of content and is verified by validation group

The remaining three areas of rigor were also addressed by this study's design and implementation. Stringer (2007) and Melrose (2001) agreed that while action research is not generalizable, it can be transferable. The generation of a concrete, refined unit of instruction combined with the documented reflection and data met the criteria of transferability. To ensure dependability, this study has thoroughly documented all activities which will occur during this study. Stringer (2007) explained that sources such as logs, journals, and instruments assist in confirming the completion of research. Not only were these sources documented but an external validation group was used throughout the study who were able to confirm the completion of research cycles.

Methodological Limitations

There are limitations to how educational action research is conducted. Educational action research is conducted through the implementation of interventions with students, collection of data, and reflection on outcomes. This requires the participation of students within a school or classroom setting. However, reflections and developed interventions are not generalizable (Mills, 2014). The goal of action research is to enact localized change and to add to the body of research surrounding its area of focus (Johnson & Christensen, 2014).

Ethical Considerations

Since action research is already performed in the normal practice of teaching (Mertler, 2014) and is designed to improve its quality (Herr & Anderson, 2005), there is a minimal risk to the students who participated. There were three data points related to students that I collected: observations, structured interviews, and formal assessment. For each data collection point, steps were taken to ensure student anonymity and protection. For classroom observations, student names and class periods as well as gender or any other identifying information were excluded from my notes, as recommended by Kaiser (2009). For formal assessments and structured interviews, an additional step was taken to ensure confidentiality. Students were assigned a unique identifier number that they used instead of their name for structured interviews and for work related to their assessment (Suresh, 2011). During the cycle, a list of the student identification numbers was kept in a secure file cabinet only accessible to another teacher in the department who recorded student participation Students were recorded using an online voicemail service. When calling the service, the students used this identifier instead of their name. As recordings were received, they were transcribed externally and then deleted. Once all student data was collected and verified, the master list containing this information was destroyed (Corti, 2008). Students and their parents had the ability to opt out if desired. These methods ensured the privacy of student data.

Researcher Subjectivities

There are some concerns related to researcher subjectivity in action research studies. The first of these is the latitude researchers gain in later cycles of the study to modify the design or planned implementation of the study (Herr & Anderson, 2005). However, as Melrose (2001) explained, the fact that a researcher modifies and interacts with the information multiple times actually increases the rigor and quality of the research. Another concern is the lack of research performed in this area as educational action research is a newer form of research (Cochran-Smith & Lytle, 1999) which could lead to flaws in design and analysis. This concern can be mitigated through adherence to qualitative and quantitative traditions and methods as much as possible throughout the design and implementation of the research (Koshy, 2005).

Educational action research places the researcher as both a generator and collector of data. This can lead to a concern expressed in many qualitative and mixed method studies, which is personal or researcher bias. To mitigate this issue, researchers must reflect on and identify their biases, as well as have others identify their biases (Rajendran, 2001). This was performed throughout in my personal reflection and with the validation group. The primary bias identified was my tendency to over-simplify some curriculum components to mitigate student failure. By identifying this before beginning the first cycle, throughout my reflections, and with the validation group; I was able to mitigate this concern and allow students to miss or fail in some cases. Student bias and concerns also needed to be addressed. The process of teaching the content to various groups of students raises a concern for equality of instruction amongst the groups. However, the nature of action research is to improve from cycle to cycle, which eliminates this concern. Additionally, students expressed concerns in reflecting and providing information on the teacher's methodology that are negative for fear of retaliation. These concerns were addressed in the design of data collection through student confidentiality.

Research Site and Participants

The research site was Blessed Trinity Catholic High School, which is located in Roswell, GA. The focus of my research was my Robotics classes, which are administered through the Business and Technology Education department. I was the primary participant in this research. Students of the Robotics classes were participants. These students were chosen because they were my students. These students were in high school and consisted primarily of freshmen with a small contingent of upperclassmen. This group was primarily male. The class size was 12 students that selected this course as one of their business electives. To gain access, approval was acquired from the Archdiocese of Atlanta, which is the governing body of private Catholic schools in the state of Georgia. Additionally, permission was obtained from the school principal.

Students were allowed to choose between this course and a variety of other business and technology courses. As such, there are some biases that should be addressed. First, Olsen (2008) explained that when individuals choose to participate (by taking the course) there is self-selection bias. Second is gender bias which Snowman and McCown (2015) described as a common occurrence in mathematics and science related courses where female students are less likely to select or participate in such courses. Finally, there was not an even distribution of grade levels of students. This imbalance might impact the responses and effectiveness of intervention, due to cognitive development differences that exist at different ages. While these biases are a cause for concern in experimental studies, Mills (2014) explained that action researchers accept such biases as an inevitable byproduct of classroom education and educational research.

Procedure

Institutional Review Board

The University Of Georgia Institutional Review Board (IRB) was established to ensure the protection of human subjects in research projects (Office of the Vice President of Research, n.d.). In order to do so, all research projects falling under the purview of the University of Georgia must be reviewed and approved by the IRB. There are three paths to review and approval; exempt, expedited, and full board review. This study applied for and received the expedited review under the guidelines specified by the IRB.

Overview

Action research involves completing four steps (plan, act, develop, reflect) in a repetitive, cyclical manner (Mertler, 2014). Throughout this process there are a variety of data points which can be collected. Because the researcher will be conducting class while researching, Herr and Anderson (2005) asserted that the data gathering process should be researcher friendly and reflect common practice of the teacher. To achieve this goal, Pine (2009) suggested that this data can come from three sources. The first source is archival data, which is information in existence or readily available such as student records, previous grades, and other administrative information. The second is through conventional sources such as interviews, observation, and interactions with students which require communication and sometimes interpretation or standardization of data. The third contains inventive sources such as designed assessments, video recordings, expositions, and other types of student work which provide deeper and more specific knowledge related to the research topic. This study focused on conventional and inventive sources of observations as the archival data does not reflect information that is relevant to this study in terms of teacher practice. For conventional data sources, I used observation and structured interviews as recommended by Mertler (2014). Another source of conventional data was personal reflections in a teacher journal as recommended by Mertler (2014) and Herr and Anderson (2005). Additionally, student assessment through a rubric designed specifically to measure student understanding of the engineering design process (Asunda & Hill, 2010) was employed as an inventive data source along with assessing the student’s engineering notebook through a rubric designed by Kelley (2013) . These data points provided information on the research questions from various viewpoints which served to assist in data triangulation. Based on the various data types being collected, students and the researcher contributed to the pool of data that I, the researcher, collected. Student data sources were the engineering notebook and interview responses. Researcher data sources were the rubrics, observation notes, and personal reflections. To assist in the interpretation of analyzed data and the development of changes, there was a validation group consisting of teachers in engineering, technology, and research fields to provide feedback on personal reflection as well as impartially grading student outcomes based on the engineering design process and engineering design notebook.

Teaching the Content

Kolb's experiental learning theory has four stages; concrete experience, reflective observation, abstract conceptualization, and active experimentation (Abdulwahed & Nagey, 2009). These stages are completed in sequence and provide students with the optimal methodology to construct the knowledge required to learn. Muscat and Mollicone (2012) described the first stage, concrete experience, as a point in which people learn through their own experience. Often times this can come from an example from childhood or an example of the concept which will be learned. Abdulwahed and Nagey (2009) describe the reflective observation stage as the watching stage. Muscat and Mollicone (2012) explained that the teaching of the content related to the concrete experience occurs at this point. Such teaching can also include research or reading for the students to further reinforce the concept. Upon completion of this step, the movement to abstract conceptualization occurs. Muscat and Mollicone (2012) explained that in this step students will start to use the information by forming ideas and plans on how it can be implemented towards a larger problem or idea. This moves the students to the active experimentation stage which Abdulwahed and Nagey (2009) described as the students actually performing or acting out their understanding of the information in an example or expirement. These four stages were the building block for the instruction in the study both for the introduction of the engineering design process as well as the design challenge the students completed.

Step 1: Introduction of the engineering design process and the design challenge.

Introducing the engineering design process. The introduction of the engineering design process followed the four steps of Kolb's learning cycle before beginning the actual engineering design challenge. This allowed the students to obtain a firm grasp of the engineering design process as a whole before implementing it on a more specific scale. The content began with students identifying a time in their life when they solved a problem. Students were then asked to think about how they went about solving the problem and to write down the process or steps they took in their own words. This was the concrete experience step in Kolb's learning cycle. Each student briefly explained the problem and their steps for solving it to the class. This drew students' attention to a pattern of steps that are logically followed to arrive at a solution. At this time, the engineering design process was introduced and explained. Upon completion of this reflective observation step of Kolb's learning cycle, the teacher modeled an example of how the engineering design process can be applied in everyday life. Students were then asked to consider what problems they could use the engineering design process to solve. This lead them from the abstract conceptualization stage to active experimentation. In this stage, the students were asked to solve the problem of what to eat for lunch using the engineering design process. Students were asked to write down each of the steps and how they would perform them based on what they understand each step to mean. This short activity provided the students with the opportunity to construct their knowledge base regarding the engineering design process before delving into a more complex challenge.

Introducing the design challenge. Upon completing the introduction of the engineering design process, students were introduced to the engineering design challenge. To illustrate the first stage, concrete experience, the students were taken outside to a field and were allowed to interact with two tools that simulate ballistic trajectories. Before the commencement of these activities, students were also given a brief lesson in the concept of scientific investigation and inquiry, which is one of the foundational principles of the scientific method as described by the *Next Generation Science Standards* (NGSS Lead States, 2013). They were asked to record their observations of the activity in their engineering notebook as these observations were used in the reflective stage. The first activity involves a JUGS© machine which is used to launch footballs to players using wheels spinning in opposite directions that force the ball into a spiral. These devices can have their speed and angle adjusted to deliver different trajectories and were the same style system that will be used in step 3, modeling the solution. Additionally, students had a two-person water balloon slingshot where they were able to launch water balloons at various angles and tensions to see a different system for launching objects and observing their trajectories. These experiences introduced the concept of ballistic trajectories as well as the relationship between angle and velocity and how they impact said trajectory.

Step 2: teaching the science and mathematics. Upon completion of the outdoor activity, students returned to the classroom where they will be asked to reflect upon their observations and to generate some basic rules or laws that they believe accurately describe their observations. This began the reflective observation stage of Kolb's learning cycle which was followed by the presentation of the engineering design challenge of shooting a ball through a target of specified height. Students performed and documented in an engineering notebook each of the steps all the way to design optimization. Students were asked to explain their ideas and possible solutions to launching the ball. At this point, the students were introduced to mathematics and science to assist them in calculating the appropriate trajectory. Additionally, students were given build plans which gave them step by step instructions on how to build the robot that will hit the ball. Upon reaching this step in the engineering design process, students would typically select the best design and then optimize it. While students performed these steps in their engineering notebook, they lack the requisite knowledge to generate a design which can properly be predicted with simple calculations. In order for students to reach a design which allows the application of predictive analysis as well as optimization, a specific design was given to the students at this time. Without this specific design, the simplified formulas developed would not work as desired. This assistance best allows students to understand and apply design optimization and predictive analysis in a controlled environment.

Step 3: modeling the solution. Upon completion of the building of their robot ball shooter, students were presented with how to calculate a trajectory based on the science and mathematic principles learned earlier. The teacher modeled this through placing a target at a specific height, performing the calculation, and then launching the ball through the target. At this point, the teacher also emphasized the importance of design optimization and demonstrated what would happen if calculations had not been used and the teacher had simply guessed the correct velocity.

Step 4: student challenge competition. After the teacher completed modeling of the solution, the target height was adjusted and students were asked to calculate and then launch their ball through the target at the new height. Students were required to record their calculations in their engineering notebook and were given three attempts to launch the ball through the target. Providing three attempts allows for some margin of error in calculation without providing students the ability to guess at the correct velocity. Students were also reminded that part of their grade is based on their documentation in the engineering notebook.

Rationale and timeline of instruction. The design of this unit is based on state and national standards for science, technology, engineering, and mathematics education as mentioned in the essential components of the engineering design process. The selection of ballistic trajectories was carefully chosen as it is a concept familiar to students through games, personal experience, and classroom activities in physics. Additionally, through the simplification of some of the formulas, this project was the easiest concept to apply to a robotics classroom. While the initial challenge was of my own design, I was assisted in completing a thorough lesson plan and refined design challenge by Kimberly Geddes, an AP Physics teacher at Creekview High School in Canton, GA (personal communication, June 8th, 2015). Based on her recommendations and calculations as well as my experience in teaching similar content, the expected timeline for completion of a single cycle of teaching can be seen in Table 3.1.

Table 3.1

Schedule of Teaching Events

Time	Step	Content
90 minutes	1	Teaching the engineering design process.
45 minutes	1	Concrete demonstrations using JUGS machine and water balloon slingshot. Students record observations.
30 minutes	2	Students reflect on observations and develop rules for trajectories.
45 minutes	2	Explanation of design challenge and students working through engineering design process.
45 minutes	2	Students will build the ball shooter.
45 minutes	2	Explanation of mathematic and scientific concepts.
15 minutes	3	Teacher models solution and shoots ball through sample target.
45 minutes	4	Students apply content and attempt to solve problem with new height.
30 minutes	4	Students will finalize engineering notebooks and reflect upon the design process as well as make recommendations for possible redesign.

Data Collection

The process of data collection can be broken down into the cycles and steps of action research as is described in the following paragraphs. For each of the cycles the data collection methods were the same and occurred at the same instructional time to ensure consistency of collection which is recommended by Elliot (1991).

Plan. In the plan step the researcher determined the content, methodology and objectives to be taught for the unit of instruction. This included the development of engineering design instructional content as well as selecting and incorporating the scientific and mathematic principles into the lesson from standards developed by the National Committee on Science Education Standards and Assessment (1996) and the National Council of Teachers of Mathematics (2000).

Act. In the act step of the cycle, the researcher taught the class (Johnson & Christensen, 2014) using the prepared materials from the planning stage and the following of Kolb's Learning Cycle as previously described[1].

[1] Instructional resources developed throughout the course of study can be requested from the author or found at http://tinyurl.com/hollersdissertationresources

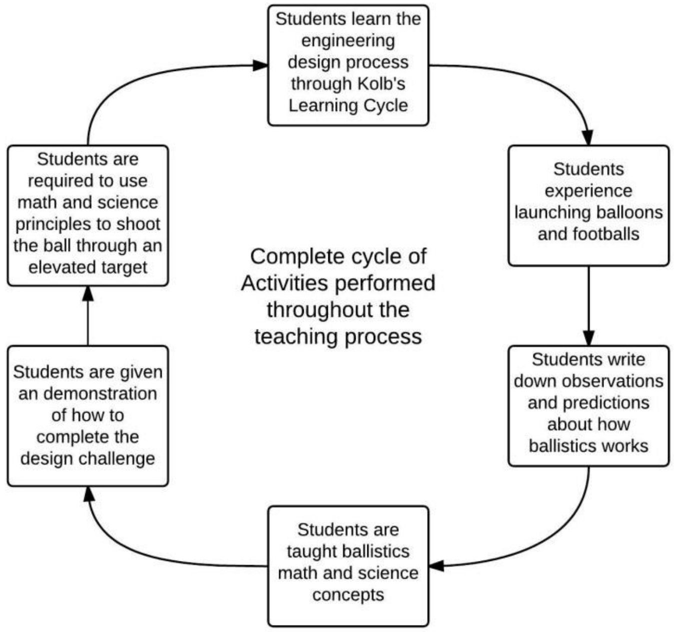

Figure 3.4. Description of learning activities conducted through the course of a single cycle of instruction.

Develop. The develop stage of the action research cycle is where the assigned data was collected and analyzed in preparation for the reflection step (Johnson & Christensen, 2014). For this step, the researcher completed observations of student work. During this stage, student work was assessed by the teacher and completed structured interviews.

Reflect. The reflect step occurs when the researcher reflects on the analyzed data and their own observations to determine what changes and improvements need to be made (Johnson & Christensen, 2014). These reflections were recorded by the researcher and then discussed with the validation group to determine which changes or improvements should be implemented in the next cycle (Herr & Anderson, 2005).

Further Cycles. Upon completion of the first cycle, the second cycle began with a new class of students as recommended by Mertler (personal communication, May 8, 2015). In reality, the reflection step in the first cycle and the planning step of the second cycle overlapped and merged in some cases as the reflection yielded the changes that resulted in modifications during the planning cycle (Kemmis & McTaggart, 2008). Upon completion of the second cycle, a third and final cycle was implemented in a third different class.

Instrumentation

There will be three primary instruments used throughout the data collection process: structured observations, summative assessment, and structured interviews. In addition, the action research process calls for reflection of the researcher on their practice (Mertler, 2014). This will generate notes and changes to the instructional practice and can be considered a fourth data point (Herr & Anderson, 2005). The instruments and a detailed explanation of their implementation can be found in Appendix B.

Structured Observations

Observation is used in standard practice by classroom teachers and is an effective means of qualitative data collection in the classroom. Johnson and Christensen (2014) explained that there are two types of observation, laboratory and naturalistic. Laboratory observation involves the setting up of a research lab for the purpose of observing controlled events. Naturalistic observation, on the other hand, involves going to where the activity being observed occurs and does not require the stringent rules and environment of the laboratory observation. Because the classroom in which robotics is taught cannot meet the requirements of a laboratory observation, such as the strict level of control required, this study employed naturalistic observation. Ary, Jacobs, Sorensen, and Walker (2014) explained that such naturalistic observation is often used in classroom studies because they can elicit a contrived naturalistic observation without the requirements of a true laboratory experiment. Multiple perspectives of the observer exist which range from the complete participant to the complete observer. They described the complete participant as one who performs the actions of the group being researched and delves themselves into the world of the observed. The opposite is true of the complete observer, who does not perform the actions of the observed, but is removed from the environment being studied. One step back from the complete observer is the observer as participant. Johnson and Christensen (2014) described this researcher as someone who will spend a short amount of time observing the individuals and informs them that they are being observed. This individual may even interact with the individuals being studied, but does not participate in their activities or actions. This observer perspective works well with this study because the amount of time spent with students is only a semester and the students will be aware they are being observed as will be required to achieve Internal Review Board approval. Upon choosing the observation perspective, Ary et al. (2014) recommended the researcher determine the type of observational data that will be collected. They explained that data from observations can fall on a continuum of quantitative, to mixed, to qualitative. The type of data is dependent on the information the researcher is attempting to gather. Quantitative methods can involve strategies such as checklists or tallying of actions or behaviors which can then be translated into numeric data (Ary et al., 2014). Qualitative methods often consist of field notes, which can take many forms and formats, but are primarily written observations. Johnson and Christensen (2014) explained that using quantitative approaches to observation allow the researcher to obtain information about specific behaviors or actions but also limit the scope of the information collected. They also explained that qualitative observation is more open-ended and exploratory in nature, but may cause the researcher to miss or not be able to gather all the available information. Mertler (2014) recommended a semi structured approach which allows for qualitative observation that includes some aspects of quantitative observation. This allowed me to obtain information about key aspects of interest related to the research questions but also allowed obtaining of in-depth information which helped in my reflection. Therefore, I used an event sampling form specific to the research questions as can be seen in Appendix B as well as field notes to complete the observation. Yount (2006) explained that event sampling serves the purpose of mitigating observer bias and providing a quick, accurate means of recording specific behaviors or achievements. Ostrov and Hart (2013) further recommended that event sampling be used to determine frequency and duration of observed behaviors. While the event sampling section of the observations, as noted in Appendix B, were used to start the research, it may be modified in subsequent cycles (Mertler, 2014). As reflection and modification of the instructional methods changes from cycle to cycle, the list was modified to reflect themes or ideas that are identified in the process of reflection and planning for the next cycle, which Mertler (2014) described as dependability of data. Such a change is a byproduct of the action research iterative process and assists the researcher in improving their practice (Herr & Anderson, 2005).

Interviews

Johnson and Christensen (2014) identified interviews as a data collection method where the researcher asks questions of a subject. While the researcher has the ability to reflect on their practice, it is also important to include student (participant) reflections in the form of interviews (Stringer, 2014). They explained interviews have two essential components to consider in their design and implementation. The first of these is the structure and environment of the interview itself which depends on the purpose and information the interviewer is attempting to gather. Firmin (2008) explained that structured interviews involve administering the same or similar questions to all the individuals being studied in a similar manner. Phellas, Bloch, and Seale

(2011) recommend the use of structured interviews because they can provide greater depth and precision than other structured types of data collection such as surveys. While Mertler (2014) explained that less structured methods are becoming more popular, the Educational Resources Information Center Digest ("Designing structured interviews", 1997) explained that structured interviews allow for quicker and simpler data collection which will be important considering the limited amount of time between research cycles. Additionally, the environment in which the interview is conducted can impact its implementation. An interviewer can conduct an interview in a synchronous or asynchronous manner (Phellas et al., 2011). Synchronous interviewing involves sitting face to face with the interviewee and asking the interview questions. Asynchronous interviewing is described by Oppendaker (2006) as independent of time and place. He also explained that this is increasingly a method employed by researchers to collect interview data. Phellas et al. (2011) also recommended the use of asynchronous interviewing as it reduces interviewer effects on subjects.

The second of the essential components in implementing interviews is the question structure. Frey (2004) described two question structures, open –ended (unstructured) and close-ended (structured). Frey explained that open-ended questions are more qualitative in nature while close-ended questions are more quantitative in nature. Johnson and Christensen (2014) described open-ended questions as those that reflect the participant's perspective in their own words. These type of open-ended questions are favored amongst researchers because it allows the participants to "fully express their viewpoints and beliefs [and it] allows participants to contribute as much detailed information as they desire" (Turner, 2010, p. 756). Turner (2010) named this type of interview as a Standardized Open-Ended interview. Such a method works well with the time constraints and goals of this study, therefore it was employed as the method of interviewing the students. Additionally, as is recommended by Trainor (2013), the questions of the interview were designed to align with the research questions of this study as can be seen in Appendix B.

Summative Assessment

Summative assessment occurs at the end of an instructional cycle and is typically used by teachers to gain an overall picture of student learning throughout the session (Mertler, 2014). Hendricks (2012) further explained that student-generated data such as projects are often used in action research to determine student understanding of concepts. Therefore, the students completed a project that requires the employment of the engineering design process, and more specifically, the optimization and analysis components of this process. These student generated solutions were in the form of a completed engineering notebook and design. The design was graded based on a rubric developed by Asunda and Hill (2007) designed to assess such engineering projects. The engineering notebook were similarly graded on a rubric designed by Kelley (2014). This project-based assessment provided insight into each of the research questions and can be found in Appendix B.

Teacher Reflection

The culmination of each cycle is teacher reflection. Mills (2003) explained that action research is about being willing to reflect critically on one's teaching on a regular basis as a means for teacher improvement. Schön (1983) studied the reflections of practitioners of various fields and found that there are two types of reflection; reflection in action and reflection on action. Reflection in action refers to reflecting upon events as they occur while reflection on action takes place after the events have occurred. Vaccarino, Comrie, Murray, and Sligo (2007) asserted that reflection in action required thinking ahead, analyzing the situation, experiencing the process, and finally responding critically with needed action. This type of reflection occurs throughout the action research cycles. Additionally, reflection on practice occurs in the reflection stage of the action research cycle and was delineated by Schön (1983) as containing three components; thinking through the recently completed situation, discussion of the situation and data collected, and recording one's thoughts in a reflective journal. In order to follow this process and in conjunction with Herr and Anderson's (2005) recommended practice of using validation groups or critical friends, I reflected upon my practice and documented these reflections in a journal which I then shared with a validation group to verify and refine my thoughts and changes that need to be made for the next cycle.

Data Analysis

In the section above, I discussed three data collection points: observations, interviews, and formative assessment through a grading rubric. In addition to these, my own personal reflections were an important part of the data generated through the action research cycles as these reflections impacted the subsequent decisions made in each planning phase and served as a focal point for the other data collected. In the analysis of the data, Mertler (2014) explained that qualitative data analysis follows an inductive process of searching for patterns and meaning in a large volume of data. This narrows the perspective to focus on those recurring themes while still keeping the holistic nature of the environment in which the data was collected. This process is also referred to by Miles and Hubermann (1994) as data reduction. The means or method of data reduction is unique to the type of qualitative data collected. Therefore, each data collection point had the time of collection which occurred during the act phase of the action research cycle followed by data reduction in the observation phase and finally reflection upon this analysis in the reflect step of the action research cycle (Mertler, 2014). This means that the data will be collected, analyzed, and reflected upon at least three times throughout the study in the manner unique to each type of data as is described below.

Interviews, Observations and the Engineering Notebook

Analysis of the observational, interview, and engineering notebook data collected was performed in two ways. For the event sampling and rubric, a basic statistical analysis was performed as recommended by Sandelowski (2000). Values such as mean, median, frequency distribution, and standard deviation were used to understand patterns of activity related to each of the components of the event sampling form and the engineering notebook. The field notes followed the processes of coding and then theme analysis as recommended by Miles, Huberman, and Saldaña (2014). This process was also used for the interview data and engineering notebook as recommended by Bogden and Biklen (2003). They described this process as working with data through organizing and breaking it up into manageable parts. Mertler (2014) described coding as reading through the data and taking note of general themes or categories of responses or information. Hoepfl (1997) called this first step of developing general themes as open coding. She further explained that these themes will become the framework for analyzing the data as it is placed into the categories. Miles and Huberman (1994) identified the next step as data display, which allows the researcher to further compress and organize the data into a system from which conclusions can be drawn. They recommended the use of matrices or networks depending on the focus and type of data. McKnight, Magid, Murphy, and McKnight (2000) concurred, especially when observing student problem solving. These matrices allow observational data to be broken into the steps of the engineering design process. Miles and Huberman (1994) identify this type of matrix as a checklist matrix. Therefore, this method of analysis was used for observational data. The use of this type of matrix allowed for greater condensation of the data and was thus less time consuming, which helped in moving quickly to the planning stage and on to the next cycle. This data display also worked with structured interviews completed by students. Since the questions were predefined, then the use of a checklist matrix best displayed the content related to the research questions (Miles et al., 2014).

Summative Evaluation

The third data point of rubric evaluation is of the quantitative type and is a summative assessment, as described by Mertler (2014). Summative assessments take place after a substantial period of time and instruction. In the case of this study, the assessments occurred at the end of the unit. The analysis of summative assessments involved the use of descriptive statistics, specifically the mean and standard deviation. Descriptive statistics summarize numerical data. This allowed me to see how the various areas of the engineering design process were affected by the intervention. The use of means showed the average class performance in a specific area, while the standard deviation helped identify outliers in the data which could skew the results (Mertler, 2014).

Triangulation

Upon the analysis of these data types, the process of triangulation occurred. Creswell, Plano Clark, Gutmann, and Hanson (2003) recommended that data collected from different aspects or viewpoints of a problem can be used to analyze the data through triangulation. In order to do so, Creswell (2005) explained that one of the more common means of performing convergent parallel triangulation is through what is known as the parallel databases variant. This is the most common means of parallel triangulation where data are collected independently but simultaneously and then the resulting analyses are compared. Greene, Caracelli, and Graham (1989) asserted that in order to perform such a comparison and method of triangulation that the paradigm from which questions are developed should be the same as the other methods of data collection. In a sense, they are saying that we need to compare apples to apples when it comes to the purpose behind the method of data collection. As a result, the data collection methods in this study are all designed with the purpose of answering the research questions. As aforementioned, triangulation uses multiple data points to understand more about the data. Once the data is collected and analyzed in its own method, the researcher looks for convergence, or overlapping of the data (Jick, 1979). To perform this analysis, Creswell (2005) and O'Cathain, Murphy, and Nicholl (2010) recommended the use of comparison matrices to understand the broader meta themes which will arise from the overlapping of the data, called the triangulation protocol. Once the triangulation protocol is complete, the final stage in the cycle was to reflect on the data so that planning began in the next cycle. This reflection took place in two parts. The first was through my own personal notes and thoughts based on the triangulated data as recommended by Creswell (2005). Additionally, this data was provided to the validation group and they were asked to reflect upon the information and make recommendations of changes as recommended by McNiff (2013).

Timing

The nature of action research requires a cyclical collection of data which will occur throughout the research process. Table 3.2 provides a general determination of when the data collection and analysis occurred. The observations occurred in the act and observe phases while the interviews and summative assessment occurred at the end of the observe phase. Because the school in which this study was conducted operates on a block schedule, classes are an hour and a half long and occur on alternating days. The act and observe phases overlapped as the act phase will include presenting the material and then allowing students to begin work. The act and observe stages took a total of 4 class days which is nine hours of class time. It is also important to note that the plan phase of the following cycle overlaps the reflection phase of the previous cycle. This is because planning changes occurred as reflection is performed.

Table 3.2

Schedule of Cycles

Event	Start Date	End Date
Cycle 1	October 5th, 2015	October 23rd, 2015
Cycle 2	October 23rd, 2015	November 13th, 2015
Cycle 3	January 18th, 2016	February 5th, 2016
Final Reflection and Observations	February 5th, 2015	February 12th, 2015

Research Question Representation

The data collected addressed various aspects of the research questions. Greene et al. (1989) recommended that when data is collected for the purposes of triangulation each type of data is chosen in a way that each one has its own unique strengths and weaknesses yet all address the same questions. This concept that they described as convergence takes different types of data and focuses on a singular question or phenomenon. Therefore, the observations, interview, and rubric data all addressed each of the research questions in their own way. By seeing each research question from the multiple perspectives of data collected, a deeper understanding of the question and its answer became visible. Because triangulation requires multiple points of data from various perspectives to gain a clear understanding of the topic being researched (Creswell, 2005), each instrument provided data for each of the research questions. This provided a clearer understanding of how each of the questions is answered. Table 3.3 shows how each instrument relates to a single research question.

Table 3.3

Relationship of Research Questions to Data Collection Methods

Research Question	Observation	Interview	Assessment
What mathematic and scientific principles did students learn?	Frequency of mathematics and science being used and observation of its application	Questions asked regarding student understanding of taught mathematics and scientific principles	Mathematic and scientific principles visibly implemented into design based on optimization of design
How did the content affect student understanding and application of design optimization and analysis?	Frequency of students applying concepts such as a decision matrix and observation of their design selection and improvement	Questions asked about student perceptions on their design and how they used design analysis	Design analysis and optimization visible in finished product and engineering notebook as graded in the rubric
How did the method of delivery of content affect student completion of the engineering design process?	Frequency of student questions and observation of student difficulties in understanding of concepts	Questions asked about student perceptions on the delivery of content and areas which they did not understand	Resulting design and engineering notebook will be graded and will demonstrate students ability or lack thereof to understand concepts
How could the content and method of delivery be improved?	Observation in teaching and during student work of difficulties and necessary reteaching of concepts	Questions will be asked about student perceptions on understanding and which components worked versus those that did not work	Resulting design and engineering notebook assessments will demonstrate areas in which students struggled or had difficulty

CHAPTER 4 DATA COLLECTION

Herr and Anderson (2005) explained that a set format does not exist for analyzing and reporting action research data. "Action research leads to a deepened understanding of the question posed as well as to more sophisticated questions. The findings should demonstrate this kind of deepened understanding, but how the researcher wants to represent them is more open" (p. 86). Developing understanding from action research data involves looking for effective means of displaying the data. Stringer (2014) added that data collection and analysis should seek to "render understandable the problematic experiences being considered" (p. 160).

The data collection and analysis for this study was divided into the three distinct cycles. Each cycle included data representation and analysis, including triangulation, reflection, and suggestions of a validation group. All cycles underwent a comprehensive analysis. Cycle analyses and the concluding analysis are described in relation to the research questions.

Mertler (2014) described the stages of action research as plan, act, develop, and reflect. This chapter focuses on these four stages of action research as completed in my study. For each cycle, I present information about my preparation (planning), how each cycle was performed (action), data and analysis (development), and changes based on prior steps (reflection).

Cycle 1

Plan

Cycle 1 planning was conducted to ensure all resources were prepared for class. I prepared engineering notebooks for students, created and refined course presentations, and set up resources required for data collection. I encountered a few challenges before the class was taught, including providing engineering notebooks to students, creating an effective water balloon launcher, and finding resources to supplement my presentations.

Engineering notebook. To purchase Engineering notebooks from a professional publisher was very expensive. To mitigate costs I made my own engineering notebooks using documents found online and distributed copies to students. Three-ring binders were used to hold documents. Binders can be reused, while pages can be pulled for easy reading and evaluation, as well as revisions. This approach substantially reduced the cost of using engineering notebooks.

Ball and water balloon launchers. I struggled greatly with developing the ball launcher that students used. Initially, my goal was to have students build their own launchers at the correct angle based on instructions. When I actually built a ball launcher, I found the motors were too slow to launch a ball any significant distance. I modified the design to enhance the gear ratio, which provided a little better launch but it was still not powerful enough to see substantial differences between various powers. I then tried creating a catapult using a kit of parts powered by rubber bands. This worked, at times, but was inconsistent. I spoke with science teachers at school and they explained that rubber elasticity is unpredictable and, thus, yields odd results. One teacher recommended using small springs as the power source. However, use of springs also resulted in inconsistent results. I purchased larger diameter tires and bigger gears to enhance the gear ratio of the catapult and allow the design to impart more force. I tested the revised catapult using a photogate as seen in Figure 4.1.1.

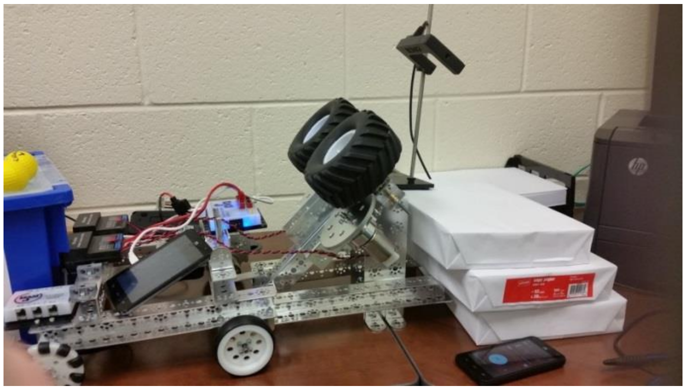

Figure 4.1.1. Final design and testing of the golf ball launcher.

This setup, while not optimal, worked far better than previous setups and actually launched the ball a significant height and distance. I calculated a table of velocities for the students using a photogate, a device that uses light to measure velocity of projectiles. I also found out that the equation used for calculating the distance had a minor flaw. I had to adjust this formula.

I purchased a water balloon launcher. Even if teachers don't have access to a jugs (football launching) machine, this is a viable alternative that students seemed excited about. I found that these water balloons are a perfect example of an innovation students could have invented. The balloons are filled in a unique way; they all connect to a single hose nozzle and fill up simultaneously. Each balloon had a rubber band holding straws that filled them and when they become large enough you simply pulled all the straws out at once and gravity did the rest. It is quick and efficient and makes filling water balloons much easier.

Act

Once all materials were ready, I introduced students to the engineering notebook and proceeded through the remaining instructional activities (see Table 4.1.1).

Table 4.1.1

Time spent in instructional activities

Activity	Time Spent (minutes)	Day(s)
Introduce engineering notebook	25	1
Present engineering design process	70	2
Launch water balloons	20	2
Football launching (jugs machine)	30	3
Student reflection and ballistics presentation	110	3-4
Engineering design challenge	110	4-5

Develop

This step involved collecting and analyzing data. Once data collection was completed and recorded, each type of data was analyzed. The resulting analysis was broken down by data type.

Observational data. Observational data in the form of duration, frequency, and field notes were collected and analyzed for each cycle. Field notes were taken throughout the cycle. The duration spent on each step and whether each step was addressed by the students (frequency) were collected during students' time working through the design process. I used open coding to analyze field notes and text-based observations. Mills (2014) explained that open coding begins by reading over all collected data and developing general categories. Mertler (2014) called this system of organization a coding scheme (p. 189). The coding scheme that emerged from my reading and understanding of the field notes resulted in four major themes:

- The engineering design process
- Ballistic trajectories
- Student reactions
- Teacher practices

Once these four major themes were identified and coded, I completed a second round of reviewing and developing themes. By focusing on these recurring themes, I developed more detailed codes that described student interaction. Mertler (2014) described this as inductive analysis, and explained that its purpose is to “reduce the volume of information that you have collected, thereby identifying and organizing data into important patterns and themes in order to construct some sort of framework for presenting key findings” (p. 189).

Therefore, the inductive analysis yields a representation of the primary themes that can then be triangulated with other data. Results of the inductive analysis I performed on the field notes are described next and can be seen in their accompanying figures.

While there were numerous student reactions to the engineering design process, one of the primary themes that was made evident from the inductive analysis was that the students felt an inadequate amount of time was spent on the engineering design process activity as a whole. Additionally, the highest occurrence of confusion was in identifying constraints and criteria. However, students did express understanding and were engaged in identifying the need and defining the problem. While there were some additional connections between student reactions and the engineering design process, these major themes were the strongest. Figure 4.1.2 shows the relationship between the engineering design process and student reactions through their interrelated themes.

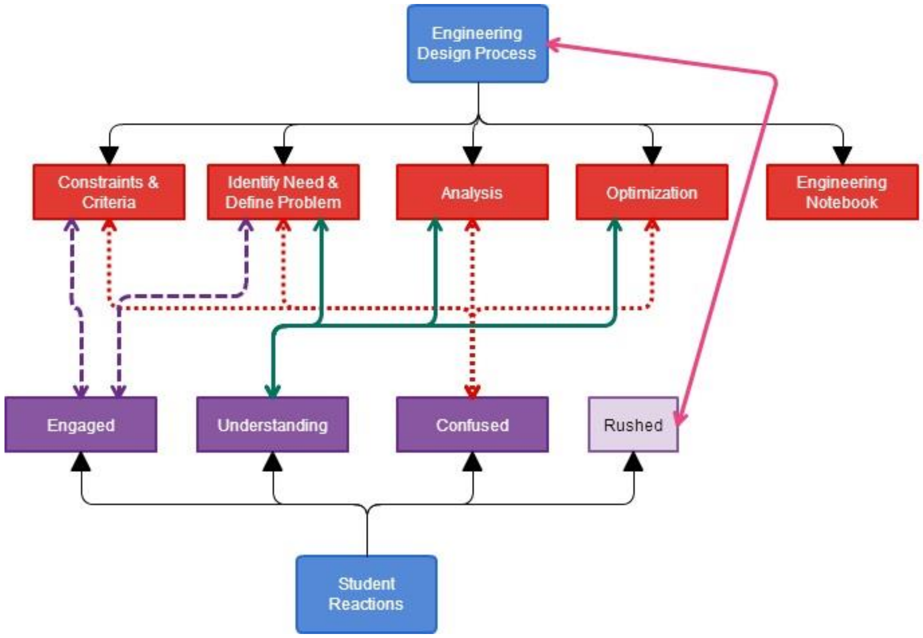

Figure 4.1.2. An inductive analysis of student reactions to the engineering design process.

The major theme of teacher practices also had specific subthemes which addressed the engineering design process as shown in Figure 4.1.3. The most prominent of these themes was that timing, or time spent on the engineering design process was inadequate. This coincides with student reactions as they felt rushed. The themes of corrections, organization, and resources are interrelated in that they address the need to revise the presentation of the engineering design process to the students.

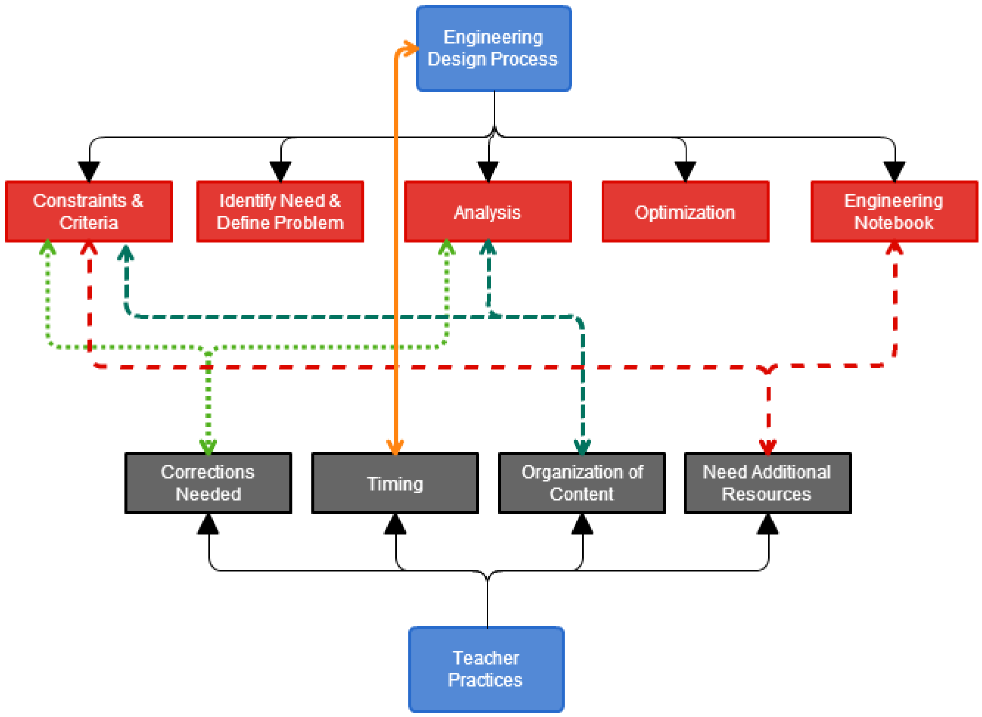

Figure 4.1.3. An inductive analysis of teacher practices to the engineering design process.

There were two primary themes related to content taught; the engineering design process and ballistic trajectories. The latter is seen in Figure 4.1.4 in relation to student reactions to the content. Student reactions to the ballistic trajectories presentation were mixed. As Figure 4.1.4 demonstrates, there was both confusion and understanding of the calculations and terminology related to ballistic trajectories. While there were 28 occurrences of understanding coded to calculations, 15 occurrences of confusion were also noted. Similarly, understanding of terminology was coded 23 times versus 7 incidences of confusion. In both cases, understanding outweighed confusion. However, there were still a significant number of occurrences that merited further investigation as to the cause of this confusion amongst students.

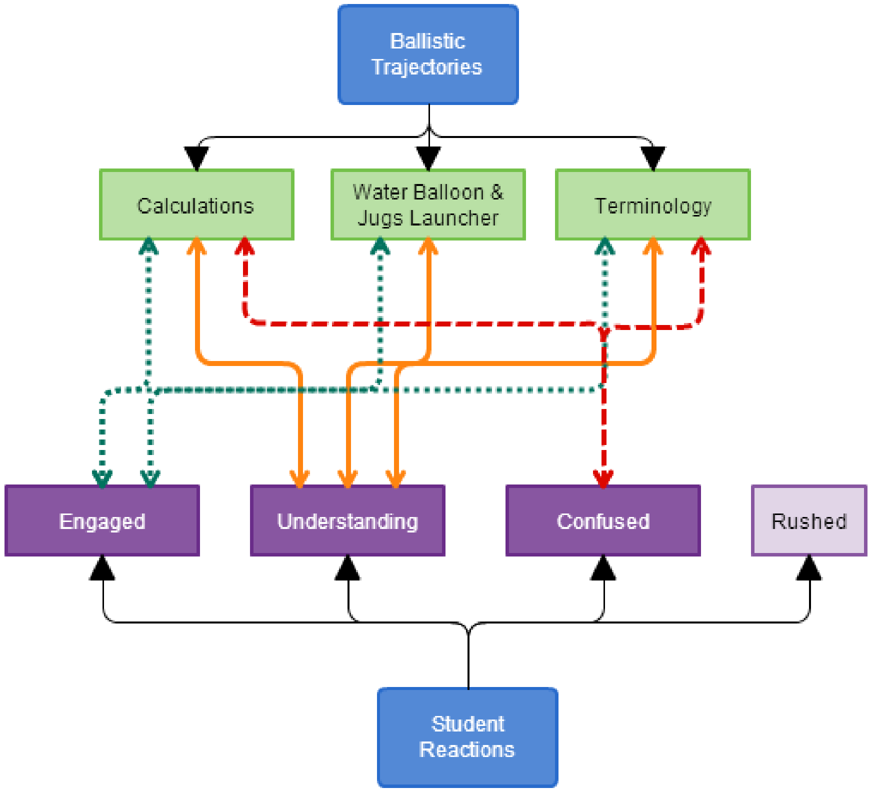

Figure 4.1.4. An inductive analysis of student reactions to ballistic trajectories.

Confusion also emerged in teacher practice. This was evidenced in the need to correct materials presented and the order of their presentation. These and other minor themes are shown in Figure 4.1.5. While of minor concern in relation to the corrections and reorganization of the presentation of ballistic trajectories, students were extremely engaged in launching the water balloons and footballs (see Figure 4.1.5). In this cycle, part of the rushing of the engineering design process occurred as a result of my attempting to get to the launching of water balloons before the end of a class, which resulted in the subtheme of *timing the activities appropriately*.

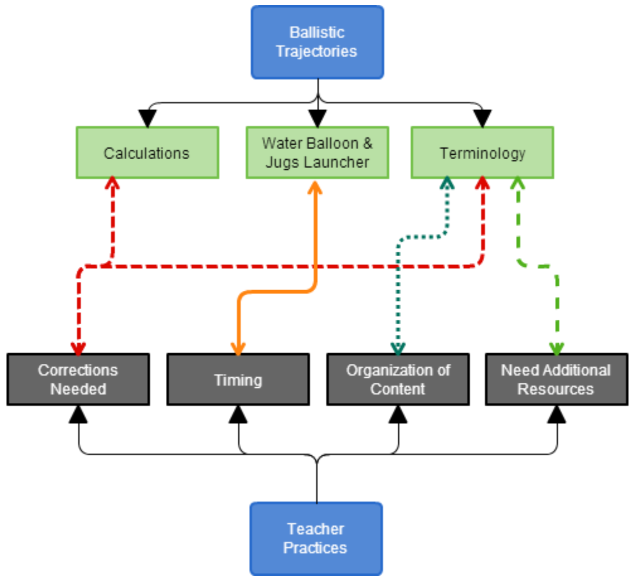

Figure 4.1.5. An inductive analysis of teacher practices to ballistic trajectories.

Observational data also included the time taken for students to complete each step of the engineering design process, referred to as duration. Additionally, I observed whether or not students were completing steps of the engineering design process. This observation was completed using frequency tallies. When completing and documenting the design challenge, students pulled up and used the engineering design process presentation as a guide to document the process. This was not by the direction of the teacher; rather the students intuitively went to this process on their own. Therefore, all students completed all steps. Time spent on the steps was tracked in intervals of short, medium, and long amounts of time. Short time was considered to be less than 10 minutes, medium time was between 10 and 20 minutes, and long time was anything longer than 20 minutes. These timing intervals were recorded in relation to their peers. To track this, I asked students to raise their hands and say what step they were on when they moved from one step to the next. The breakdown of each step and the number of students for each duration can be seen in Figure 4.1.6.

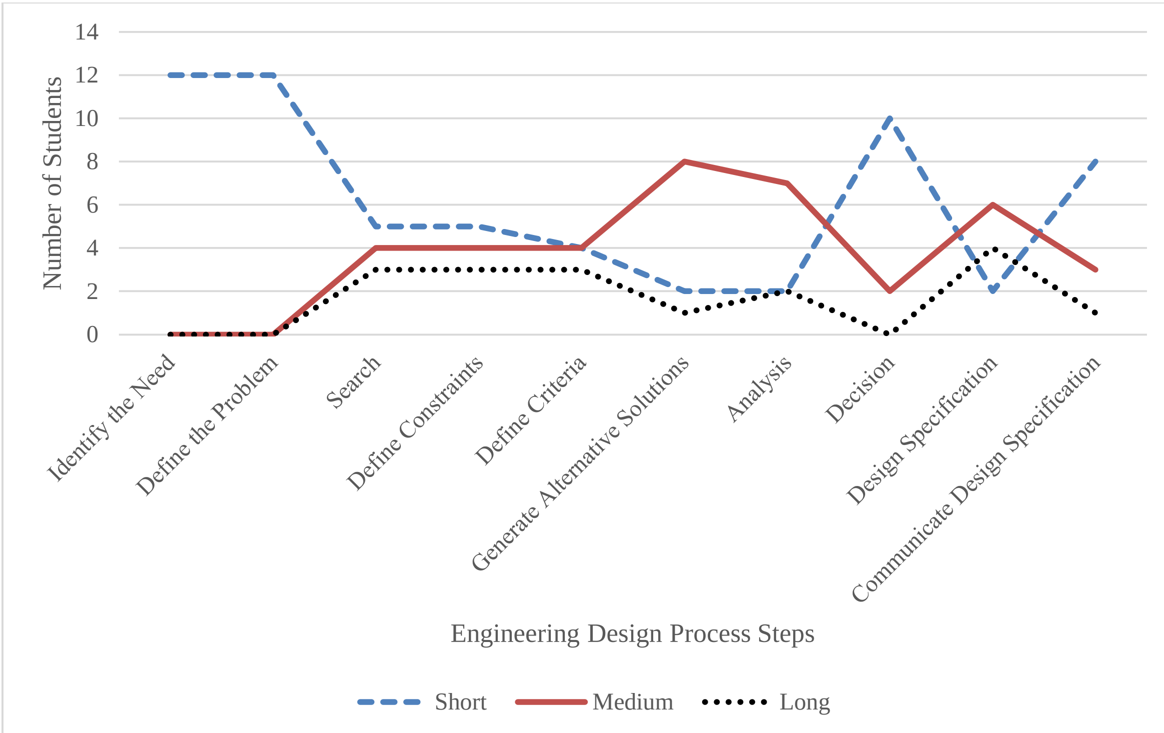

Figure 4.1.6. Duration spent on engineering design process steps by number of students.

Student engineering notebooks. Student engineering notebooks presented a combination of quantitative and qualitative data. Qualitative analysis of the engineering notebooks consisted of open coding. Because notebooks dealt specifically with the engineering design process, they were broken into the individual steps for coding. This allowed a cross-referencing of each step with other students' to determine common themes. In Table 4.1.3, each step is listed, as well as themes that emerged from coding. Ryan and Bernard (2003) explained that meaning can be derived from what is not mentioned in data. They explained that this can be attributed to lack of knowledge or omission by the generator of the data. As a teacher, there are often expectations of what student responses will include. Each step of the engineering design process had requirements or expectations for what should be documented as described in the rubric. While coding can and should include themes which are present, the absence of expected responses is itself a theme as well. Therefore, the missing themes column in Table 4.1.2

describes the themes which are developed from a lack of student response based on the aforementioned expectations.

Table 4.1.2

Themes by Step of the Engineering Design Process

Step	Themes	Missing themes
Identify need	Launching a ball through a target, Specific distance and height	Mention of stakeholders, global implications of need
Define problem	Make/design a machine/robot that launches a ball, Follow a specific trajectory or cover specific distance	Should not include specific solutions, Well developed problem statement
Search	Completed a patent search	Address the problem space
Constraints	Parts in the robotics kit, Cost, Durability	Size, Cost is not a constraint, Launch Angle
Criteria	Accuracy, Consistency, Launch at 45 degree angle	Launch angle is a constraint
Generate possible solutions	Possible options: Slingshot, Catapult, Flywheel with motor, Swinging hammer, Compressed Spring	None identified by the researcher
Analysis	Students documented calculations	Failure to divide distance by 2, Corrections to original calculations
Optimization	Students completed a decision matrix	None identified by the researcher
Decision	Most popular solution was slingshot then catapult. Students mentioned reasoning as best solution possible.	Thorough, descriptive rationale for selection
Design specification	Most included diagrams of solution or device, Some included descriptions	Detailed and organized specification which adequately describes function.
Communicate design specs.	Description of the device, Reference to stakeholders or people who would use the device	None identified by the researcher

Engineering design and engineering notebook rubrics. Two independent rubrics were used to grade students' design challenge production and engineering notebooks. These were analyzed quantitatively by calculating the mean, median, mode, and standard deviation of each grading category as well as the grades overall. Figure 4.1.7 shows the average grades in each section of the engineering notebook rubric. Table 4.1.3 provides descriptive statistics for the engineering notebook grades by section.

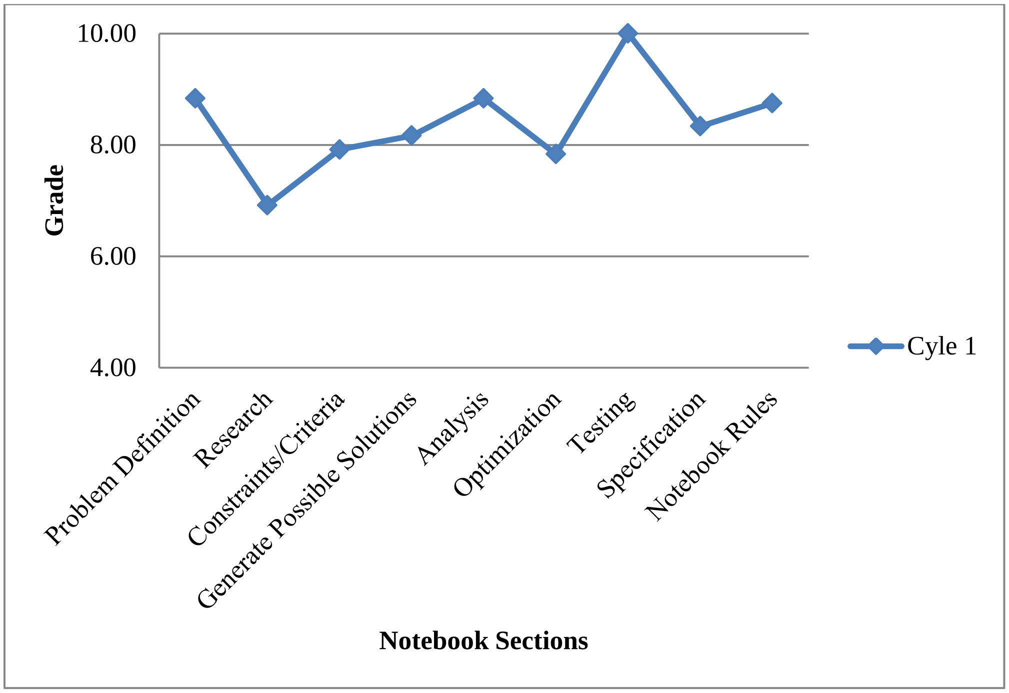

Figure 4.1.7: Chart of engineering notebook grades by category for Cycle 1.

Table 4.1.3

Statistical Analysis by Category of the Engineering Design Notebook.

	Class average	Standard deviation	Mode	Median
Problem definition	8.83	1.53	10	9.5
Research	6.92	3.32	10	7
Constraints & criteria	7.92	3.82	10	10
Generate possible solutions	8.17	1.90	10	8
Analysis	8.83	2.12	10	10
Optimization	7.83	2.89	10	10
Testing	10	0	10	10
Specification	8.33	1.72	10	8.5
Notebook rules	8.75	1.76	10	9.5

A total score was also calculated. The class mean was 84.0 with a standard deviation of 16.29. The mode was 100 and median was 90. Grades were calculated on a scale from 0-100.

I compared the students' grades both using the engineering notebook rubric and the engineering design rubric. Both rubrics are designed to assess students' completion and documentation of the engineering design process. This resulted in students' grades being nearly identical in all areas in which the rubrics overlapped (see Table 4.1.4). Because these grades are redundant, there is not a need for the engineering design rubric. Mills (2014) called this interim analysis and explained that a researcher should stop periodically and determine whether or not the data collection tools being used are actually collecting meaningful data. Results of this interim analysis was the continued use of the engineering notebook rubric as a means of assessment and data collection, primarily because it included all steps of the engineering design process and evaluated student application of engineering notebook rules. Use of the engineering design rubric's was discontinued.

Table 4.1.4

Comparison of Engineering Design Rubric and Engineering Notebook Rubric

Engineering Design Rubric	Engineering Notebook Rubric
Design Product: Design Requirements	Problem Definition
Design Product: Workmanship	Students did not build the design
Design Product: Creativity	Brainstorming / Idea Generation
Design Process: Research	Research
Design Process: Criteria and Constraints	Constraints and Criteria
Design Process: Idea Generation	Generate Possible Solutions / Idea Generation
Design Process: Mathematical Models	Analysis
Design Process: Prototyping	Prototype
Design Process: Iteration	**Not included**
Communication: Reports / Documentation	Specification
Communication: Design notebook entries	The entire rubric
Teamwork	Students worked individually
Not included	Notebook Rules

Student interviews. Student interviews were conducted through Google Voice and then transcribed and coded in the same manner used for the observational and field note data. For this cycle, one student did not complete the interview. Since student anonymity was maintained, I was unable to determine the student who did not complete the task. I did ask students to complete the interview multiple times and provided multiple to do so.

Overall, students were asked 12 interview questions. The average time spent answering questions was approximately four minutes and eight seconds. When recording their interviews, students did encounter some issues. The voicemail service, Google Voice, limited student responses to four minutes. I was informed about this limitation by students after I asked them to complete the interviews. Students were able to work around this issue by calling multiple times and finishing their interviews. There was a mix of lengths as some students took only two to three minutes, while others took up to eight minutes. No interview lasted over 10 minutes. I developed a solution to counteract this issue.

Much like the engineering notebook, interviews were divided naturally by questions. Each question was analyzed by developing themes from responses. Table 4.1.5 summarizes each question and the themes developed from coding the responses.

Table 4.1.5

Interview Questions and their Related Themes

Question (summarized)	Themes
Describe the engineering design process.	It's a problem solving process, Attempting to find the best solution
Which steps of the engineering design process are scientific?	Analysis, The engineering design process is similar to the scientific method
What scientific concepts did you use in these steps? (from previous question)	Ballistic Trajectories, Calculations for launching the ball
Which steps of the engineering design process required math?	Analysis
What mathematical concepts did you use in these steps (from the previous question)	Completing the calculations: Using distance, height, and velocity to complete calculations
What does optimization mean?	Finding the best solution, Using constraints and criteria to pick best solution
Describe what was hard and easy about optimization.	Hard: Making a decision, identifying and weighting criteria and constraints Easy: Filling out a decision matrix Most found process to be easy
What is analysis?	The use of math and science, the engineering design process
Described what was hard and easy about analysis	Hard: Math and calculations Easy: Math and calculations
What were helpful and hard parts of learning engineering design process?	Helpful: teacher examples Not Helpful: presentations and videos in presentations
Is there anything the teacher could have done better?	Need more time to practice calculations, Presentations could be improved, Rushed
How can you use what you learned in the real world?	No consistent themes

Triangulation. Triangulation uses multiple data points to understand more about the data. Once data is collected and analyzed, convergence, or overlapping in the data is reviewed (Jick, 1979). The themes derived from the various data points converged upon teacher practice and materials as key areas that might need change. The first convergence was in the rushed presentation of the engineering design process. Lack of clarity, organization, and presentation of the engineering design process and ballistic trajectories were also themes which emerged from the data analysis. Creswell (2005) and O'Cathain et al. (2010) recommended the use of triangulation matrices to represent the overlap of themes from the data sources. Since the focus of action research is to improve teacher practice (Mertler, 2014), the triangulation protocol focused on the areas of teacher practice: the engineering notebook, the engineering design process, ballistic trajectories, and the design challenge. The first triangulation matrix represented in Table 4.1.6 demonstrates the overlap of themes which occurred in relation to the engineering notebook.

Table 4.1.6

Triangulation Matrix of Emergent Themes in the Engineering Notebook Activity

	Triangulated theme	Themes by data type		
		Observations / Field notes	Engineering notebook	Student interviews
1	Students did not apply all rules appropriately	Students confused about documentation, student questions required repeating rules	Multiple missing signed pages, multiple rule infractions across notebooks	Not mentioned by students

The primary area of overlap, (see Table 4.1.7), was that students did not apply the rules correctly in all circumstances. While the class average was 8.5 out of 10 on notebook rules, which demonstrated a general understanding, there were some simple errors which students could have avoided. While there was only one convergent theme in the engineering notebook section of the lesson, there were a larger number of convergent themes surrounding the engineering design process. It is important to note that documentation of the engineering design process was covered as a part of the engineering design process. Therefore, themes related to documentation of this process are included in this section as well as the design challenge section where the documentation actually occurred. Table 4.1.7 demonstrates the engineering design process triangulated themes and their sources.

Table 4.1.7

Triangulation Matrix of Emergent Themes in the Engineering Design Process Activity

	Triangulated theme	Themes by data type		
		Observations / Field notes	Engineering notebook	Student interviews
1	Students lacked thorough documentation of the engineering design process	Student questions expressed confusion and asked for clarification.	Several steps lack thorough and proper documentation, high level of variance in student grades, several steps had inconsistent and diverse answers which should yield similar results.	No data
2	Spend more time on the engineering design process	Teacher observation of rushing through the steps of the engineering design process.	Lack of consistency and thoroughness in documentation, Student responses incomplete or lacking in rigor.	Engineering design process was rushed
3	Videos created confusion and were not helpful	Teacher observed that videos did not coincide with engineering design process steps, students seemed bored and confused.	No data	Videos created confusion and were not helpful in understanding concepts
4	Students enjoyed practical application	Students were engaged and excited when launching the water balloons and footballs.	Documentation of this component of the process was thorough and displayed an understanding of the basic concepts of trajectories throughout the entire class.	JUGS / Water balloon activities described as fun and helpful
5	Students understood and applied the engineering design process	Students were able to document and apply the engineering design process and launch the ball through the target successfully	All steps were followed and documented in student engineering notebooks	Students were able to correctly define the engineering design process, optimization, and analysis

The primary concern that emerged from the triangulated themes was that while students demonstrated a basic knowledge and understanding of the engineering design process, there was a lack of thorough documentation of the process. Additionally, there were instructional themes centered on rushing through the presentation and a lack of utility of the videos in the presentation. The ballistic trajectories theme overlap occurred primarily with teacher resources and how they were organized and taught (see Table 4.1.8). Despite these difficulties, all students were able to properly calculate the trajectory provided.

Table 4.1.8

Triangulation Matrix of Emergent Themes in the Ballistic Trajectories Activity

	Triangulated theme	Themes by data type		
		Observations / Field notes	Engineering notebook	Student interviews
1	Students understand general rules of projectiles	Students demonstrated understanding of projectiles	All students were able to identify general rules of trajectories correctly.	Ballistics described as an easy concept.
2	Organization of presentation content was confusing	Teacher observed organization of presentation as confusing, Students asked for clarification and expressed confusion.	No data	Ballistics presentation described as not helpful.
3	Videos and other materials in presentation caused confusion	Videos too long, videos did cover concepts adequately, student fell asleep or were bored during videos.	No data	Videos described as distracting and not helpful.
4	Students able to correctly calculate trajectories	All students were able to correctly calculate ball trajectory and launch successfully.	Calculations performed correctly and documented in the engineering notebook	Students described calculations as an easy step.

The transition to application of the engineering design process and ballistics also resulted in some emergent themes. One major overlap occurred between the engineering design process presentation and its application in the design challenge. Students struggled with properly documenting the steps of the engineering design process. Additionally, while students expressed understanding of how to perform the ballistic calculations in the ballistics presentation, half of them incorrectly calculated the distance because they forgot to find the midpoint of the range, rather than the entire distance covered. However, the most strongly represented theme was the lack of student understanding of external relevance of the activity. Students lacked the ability to describe nearly any external relevance of this activity.

Table 4.1.9

Triangulation Matrix of Emergent Themes in the Design Challenge Activity

	Triangulated theme	Themes by data type		
		Observations / Field notes	Engineering notebook	Student interviews
1	Students understood the challenge	Students quickly moved through Identify the Need and Define the Problem.	Most students defined the problem in similar, correct terms.	No data.
2	Students found examples used useful	Students demonstrated understanding of examples and related them to concepts taught.	Students were able to define the problem and identify the need in most cases.	Students described examples used as useful or helpful.
3	Students confused on completion and documentation of the engineering design process	Students required clarification and assistance and asked multiple questions about how to properly document steps.	Low average scores with high standard deviation in multiple steps, Large amount of inconsistency in student documentation and responses.	No data.
4	More practice needed with calculations	Students would set up the wrong distance multiple times on the first attempt and then would come back with the correct distance.	6 of 12 students incorrectly calculated the distance and had to make corrections.	Students requested more time to be spent on practice calculations
5	Students lacked understanding of external relevance	Students asked how the content taught was relevant to them.	Students unable to identify external stakeholders for challenge.	Multiple students unable to identify any external relevance.

Reflect

Reil (2016) provided a description of how to document action research. In her structure the reflection stage plays a critical role in the improvement of practice and should be documented in each cycle. Reflection is "looking back on your action after collecting data [and asking the questions] what thoughts come to mind? If you were to repeat the process, what would you change? What worked best for you? What most surprised you?" ("A written report", para. 11). A final reflection that addresses the research questions and study as a whole is often included once the research is concluded. "Solid action research leads to a deepened understanding of the question posed as well as to more sophisticated questions. The findings should demonstrate this kind of deepened understanding, but how the researcher wants to represent them is more open" (Herr & Anderson, 2005, p. 86).
They further explained that committees will often desire to have findings documented in a specific chapter or specific way but that the researcher must select the means of communicating the depth of information both in context and as a whole. Therefore, for the reflection stage, I explained my reaction to each of the major themes that emerged from the analysis, answering Reil's (2010) question regarding what I would change. I explained my reflections on what did and did not work as well as any surprises encountered throughout the cycle.

The themes that emerged during analysis of data led to reflection and development of changes for the next cycle. Since these themes were addressed in order of when the activity was taught, I continued with this order in describing these changes and reflections.

Engineering notebook changes and reflection. Few changes were needed to the engineering notebook activity. Students were able to document and follow the rules. There were only two incorrect scratch-outs from the notebooks and the primary loss of points came from students not signing each other's pages at the end of each class. While an average score of 8.5 on the notebook rules is lower than desired, it is still above the other categories in the grading rubric for the engineering notebook. There were few questions regarding the notebook and most students seemed to understand its purpose and use.

Engineering design process changes and reflection. Students struggled both in practice and in application of the engineering design process to document the steps thoroughly. I taught this concept by allowing students to choose their own example and then walked them through the documentation process. The problem with this approach was that students lacked a uniform standard from which they could clearly understand and develop their documentation. Since each student problem was unique, there was not enough time to address every step of students' documentation. Therefore, I determined that using a single example would provide students a consistent, predetermined solution. This solution allowed students to have a common ground for understanding the process, rather than completing the task with little assistance from the teacher. This is much like the process used in mathematics classes where a teacher will walk the students step-by-step through a predefined problem to ensure understanding before giving students a unique problem that applies the same principles. I used the water balloon filling device as a common example as it relates directly to the water balloons they would launch.

Another theme that emerged was that the engineering design process presentation was rushed. In my desire to engage the students, I told them about the water balloon launcher before I presented the engineering design process. While the students were initially interested, they became restless as the presentation proceeded. I also felt that I needed to rush through the presentation to ensure that the class reached the water balloon activity. Students mentioned that the process seemed rushed and wanted more time to discuss the process and its documentation. I determined that a possible solution was to not mention the water balloon activity until it was time to go outside. By refraining from creating such an artificial deadline, more time was spent on the lesson.

Another concern expressed by students and myself was that videos used in the presentation caused confusion. While students expressed interest in the video series, it does not cover the complete engineering design process. Therefore, eliminating the videos alleviated confusion. However, removing the videos also left the presentation lacking a fun and engaging representation of the steps. New videos that adequately explained the engineering design process were included.

The remaining two concerns address questions posed by students during the engineering design process. The first concern related to the idea generation step. Multiple students mentioned that they had already generated ideas before reaching that step. One student even came up during class within a few minutes of starting the activity with a solution already drawn up. An informal poll of the students resulted in 8 of 12 students already having an idea for a solution before reaching this step. Hynes, et al. (2011) explained that this is a normal reaction of students when posed with a problem. They further explained that students should not rush to develop solutions, rather they should gain a better understanding of the problem by following the process. Therefore, I explained to students that ideas can come at any step and they should feel free to write those ideas down, but they should continue in the process and revisit their ideas at the appropriate step. I also made the point that these premature ideas should be designated in some way so they are able to return to them easily. This allowed students to record these impulse ideas and then continue through the steps, which conserved the ideas and reinforced the importance of completing the steps in order.

The second concern regarding the engineering design process was that a number of students attempted to complete the decision matrix in the generate criteria step as was described in the presentation. While the matrix can be constructed, it is actually completed in the optimization part of the analysis step. Therefore, I moved the discussion of the decision matrix to the optimization part of the presentation.

Ballistic trajectories changes and reflection. Reflection on the ballistic trajectories activity resulted in a need to changes the organization, timing, and content of the activity. The first change to address is the order change of the material. As my presentation progressed students became bored, some even placed their heads on the desk. Additionally, some students expressed difficulty in following the purpose and reason behind the concepts being taught, which was evidenced by their questions. Based on this confusion, the presentation was reorganized to introduce basic terminology and the concepts which were most important first. Once students understood the terminology and how to perform calculations, the background information such as Newton's Laws of Motion were introduced. Witzel, Mercer, and Miller (2003) explained that organization of instruction from grounded, concrete concepts to more abstract theory assists students in learning math concepts. Hartman and Glasgow (2002) explained that this method is also effective for teaching science concepts.

The ballistic trajectory presentation included a variety of videos to reinforce the concepts being taught. However, these videos caused confusion about the content. Some videos presented ideas outside the scope of the lesson, which prompted student questions about what was necessary to understand for the lesson. While most of the videos were removed, the Newton's Laws of Motion video was kept as students expressed understanding and enjoyment of the video.

Another concern, expressed both in this activity and the design challenge activity, was that students required more practice completing ballistic trajectory calculations. Therefore, more time was spent practicing the calculations with a wider range of values.

Engineering design challenge changes and reflection. While students were all able to complete the design challenge and launch the ball through the target correctly, there was significant confusion throughout the process. A number of questions centered on how to perform the ballistic calculations. Six of 12 students miscalculated the distance on their first attempt. This theme was addressed through increased practice time for the ballistic trajectories activity.

Multiple students expressed confusion regarding documentation of the engineering design process. While the rubric was provided, there were still multiple questions. Most did not understand what to write for each step nor did they document them thoroughly. This was evidenced by my observations, lack of time spent on steps, and student questions. The order of predictive analysis and launching also caused confusion. The calculations and launch were performed once students had documented all the steps of the process instead of during the analysis and design specification steps. While this order sought to keep students from focusing on the completed prototype as a solution, the side effect was confusion. To mitigate this confusion future cycles used a single example to learn the engineering design process and a documentation guide to provide clarity for documentation requirements. These changes were coupled with launching the ball in the design specification stage. Since the launcher is a prototype, this aligns with Hynes et. al.'s (2011) assertion that prototyping can occur at this step.

Another major theme was students' inability to identify the practical application of the challenge. This was consistent both in student reaction in class and in interview responses.

Therefore, an engineering design challenge with practical meaning was developed. Dude Perfect, a YouTube channel that involves a group of young men performing “trick shots” using various sports equipment provided such a challenge. The redefined problem statement explained that the young men from Dude Perfect wanted to make a trick shot on the first try with a golf ball. As an example, a video in which the Dude Perfect actors use ping pong balls to perform trick shots was shown, which clarified and provided inspiration for the challenge. This design had the added benefit of creating a more abstract design challenge. Hynes et. al. (2011) explained that such challenges require students to think more critically and thoroughly about the problem.

Validation group. McNiff (2013) explained that critical friends or a validation group should be used in action research to enhance the validity of the research and to assist the researcher in making the correct decisions about changes from cycle to cycle. Therefore, I established a validation group consisting of two teachers with doctoral degrees, two science teachers (one of whom has a doctoral degree), and a math teacher. Once I analyzed the data and reflected on emergent themes, I met with the validation group to explain proposed changes. After explaining the study and what transpired, one committee member engaged me in a conversation about the study’s validity. This individual’s research experience was based in quantitative research. He questioned why there were not separate test and control groups, as well as some other aspects of the experimental designs. After a few minutes of discussion I was able to alleviate most of his concerns. He did remark at the end of the meeting that he could see the practical implications of this methodology for teachers. I explained and defended the changes I made.

We first discussed the concern of students’ inability to understand the practical relevance of the engineering design process. The panel agreed that the end of the engineering design process would be an ideal location to point out the relevance of the activity. They agreed that the updated design challenge would help point students to a more practical application of the knowledge. The next concern that arose was students' lack of clarity as to what parts of the activity were scientific. One such scientific concept was scientific inquiry, which is a Next Generation Science standard (NGSS Lead States, 2013) and occurred in the observation of the water balloons and footballs as well as the first three steps of the engineering design process. Finally, the panel believed that emphasizing the interrelatedness between math and science in the analysis and optimization steps was important. No other concerns were expressed regarding the suggested changes.

By the conclusion of the meeting, the group generated the following modifications to the activities:

- Idea generation can occur at any time in the process and should be documented.
    - These ideas should be marked using a square, circle, or asterisk for easy identification in the future.
    - This should be mentioned before the engineering design process steps are taught so that students understand that it is a creative process.
- Include a video or other resource at the end of the engineering design process presentation that explains how engineers use the process to solve global problems.
- Have students self-grade using the rubric after walking through the practice example of the engineering design process. This should help them better understand the requirements and criteria for documentation and grading of the notebook.
- Emphasize the concept of scientific inquiry in the first three steps of the engineering design process as well as during the observation of water balloons and footballs.

Cycle 2

Plan

I spent approximately four days updating the presentations and making the recommended changes to resources and practices. I was able to find a video to replace the explanation of potential and kinetic energy for the ballistic trajectory presentation that is shorter and more closely matches the concepts being discussed. I also ordered more water balloons and prepared the engineering notebooks. To account for variance in the launcher design accuracy, I increased the height of the opening in the target.

Act

Upon completing these changes, I began teaching the new class of students. We covered topics in the same manner as before with updated presentations and strategies. While the first cycle took five class periods to complete that were approximately 90 minutes each, the second cycle took seven class periods of a similar duration. Table 4.2.1 shows the time spent in each section compared to Cycle 1.

Table 4.2.1

Time Spent in Instructional Activities in Minutes

Step	Cycle 1	Cycle 2
Introduce engineering notebook	25	45
Present engineering design process	70	135
Launch water balloons	20	45
Football JUGS launching	30	30
Student reflection and ballistics presentation	110	105
Engineering design challenge	110	200
Total Time Spent	365	560

Overall the second class spent more time in nearly all areas of instruction. This was especially true in the introduction and application of the engineering design process. The ballistics presentation took less time because multiple videos were removed. Therefore, actual instructional time increased as students completed multiple practice attempts with the calculations. Additionally, increased discussion time was spent on vocabulary and other concepts presented. When presenting the engineering design process, a single example was used and the class discussed the proper documentation of each step. Also included was an example decision matrix (see Figure 4.2.1).

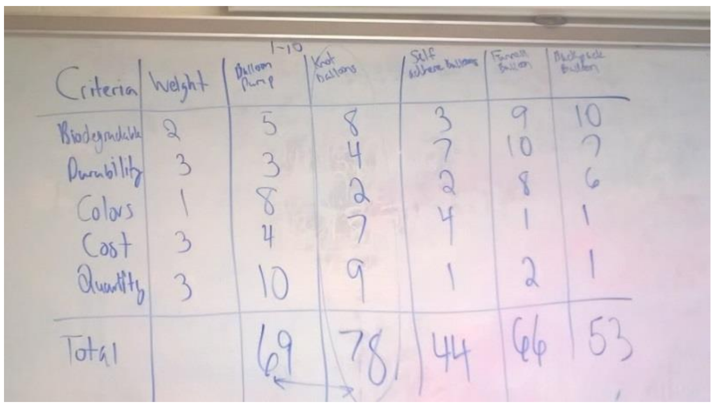

Figure 4.2.1. Demonstration performed on board of decision matrix.

These aspects caused a substantial increase in time spent and quality of documentation for this activity.

Develop

Observational data and field notes. Observational data in the form of duration and field notes were collected and analyzed in the same manner as Cycle 1. Frequency of students completing the engineering design steps was not recorded as all students completed all steps. The coding scheme that emerged from my reading and understanding of the field notes resulted in four major themes.

- The engineering design process
- Ballistic trajectories
- Student reactions

- Teacher practices

Inductive analysis on the themes of the engineering design process and student reactions yielded both similarities and differences when compared with Cycle 1. Overall, student confusion was not as prominent and focused primarily on documentation as a whole as well as the search, constraints, and criteria steps. Understanding as a whole increased, especially for identifying the need, defining the problem, and generating ideas. Student inquiry emerged as a new theme, specifically in regards to the engineering notebook. This inquiring was primarily about how to properly document the engineering design process. Also, with the revised explanation of how idea generation should occur, students inquired about and understood this new concept.

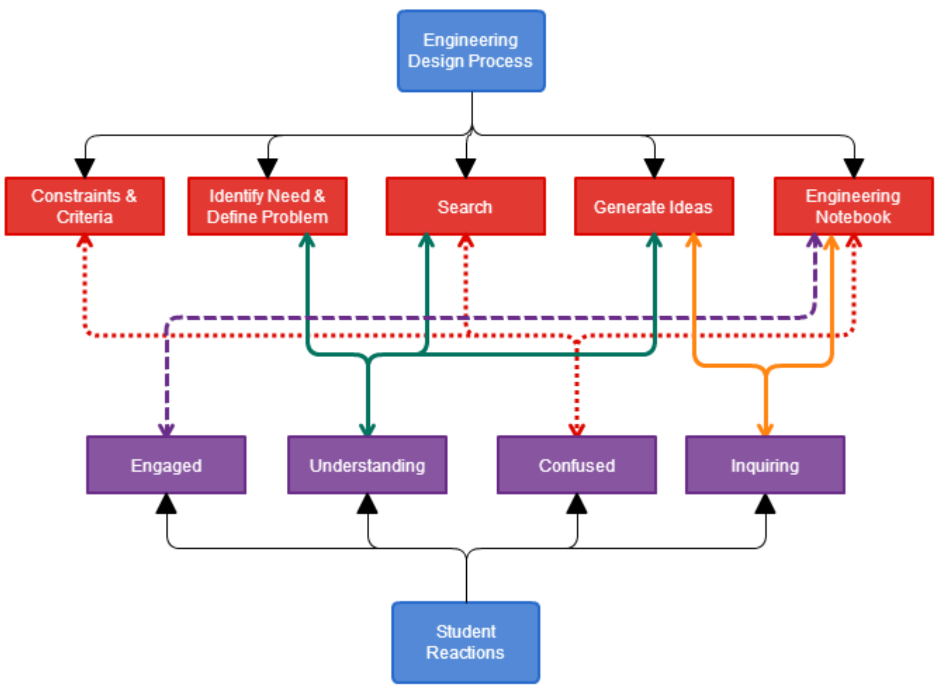

Figure 4.2.2. An inductive analysis of student reactions to the engineering design process.

The number of themes and their overlap decreased from last cycle for teacher practices in relation to the engineering design process. The timing of the engineering design process, which was a concern from last cycle, remained a theme. However, this theme differed as timing was perceived as effective and useful rather than negative or rushed. The other primary theme was the need for better resources or explanation (corrections needed) of the constraints, criteria, and search steps. It was also evident from this theme that a resource for assisting in documentation of the engineering design process was needed.

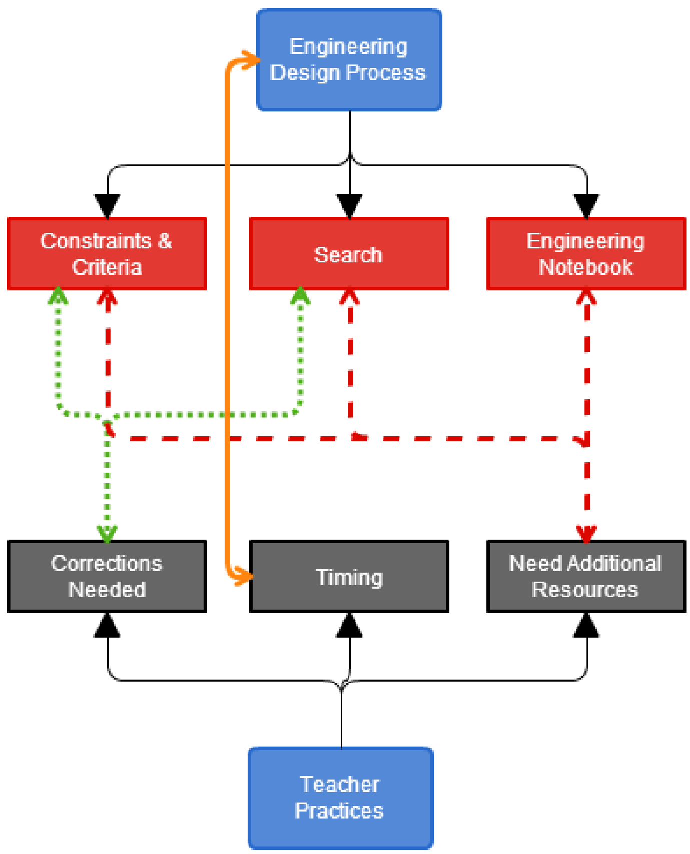

Figure 4.2.3. An inductive analysis of teacher practices to the engineering design process.

The ballistic trajectories and student reaction theme interaction simplified dramatically from last cycle. The primary concept that emerged was that of understanding. Students better understood the terminology and calculations than the previous cycle. However, there was still a minor theme of confusion with calculations. When attempting to calculate trajectories, students were still forgetting to divide the distance in half.

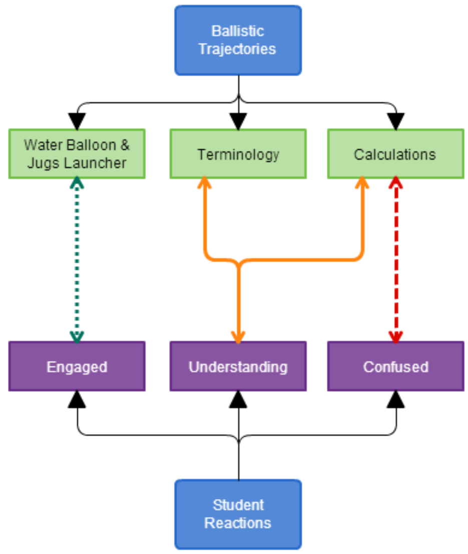

Figure 4.2.4. An inductive analysis of student reactions to ballistic trajectories.

Ballistic trajectories also saw a simplification in themes and their interactions with respect to teacher practices. The primary theme was that students were still struggling with calculating the distance properly in their ballistic calculations.

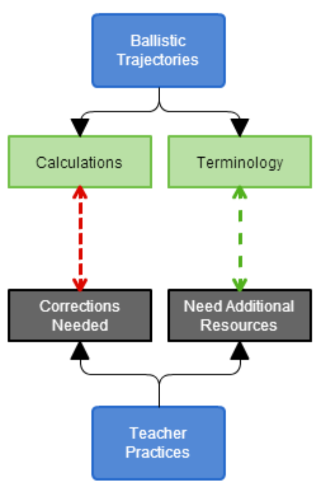

Figure 4.2.5. An inductive analysis of teacher practices to ballistic trajectories.

To track duration, I performed the same process used in Cycle 1 by having students raise their hand and state the step they were on when they were moving from one to the next. While this process was helpful, there was some difficulty in determining exactly what short, medium, and long should be and which students should fall into those categories. A recommendation for modification of this process to include more detail in the data collection was presented in my reflection. Duration was broken into short, medium, and long timing. The breakdown of each step and the number of students for each duration level is in Figure 4.2.6.

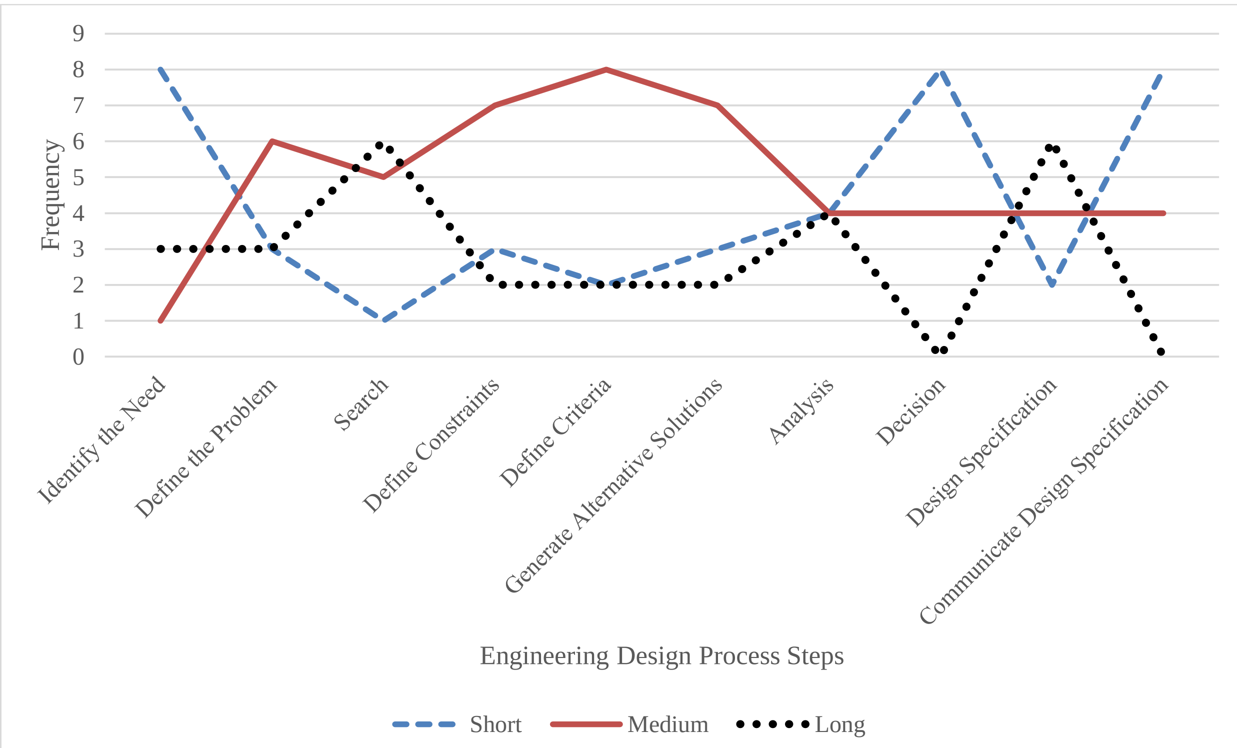

Figure 4.2.6. Time spent by duration on each of the engineering design process steps.

Student engineering notebooks. Open coding was used to analyze engineering notebooks. Those themes which appeared in the students' writing appear in the themes column while themes that were not included but were expected appear in the missing themes column. In Table 4.2.2, each step and its themes are described.

Table 4.2.2

Themes by Step of the Engineering Design Process

Step	Themes	Missing themes
Identify Need	Dude Perfect people are stakeholders, the need is to make a trick shot	Global implications of need
Define problem	A trick shot must be made on the first try, the shot is hard, the ball must follow a specific trajectory	Well-developed problem statement.
Search	There are existing solutions, A patent search was performed, URLs of solutions included, solutions that propel or launch	Lack of depth in defining problem space, primarily focused on existing solutions to golf ball launching
Constraints	Size or weight, durability, cost, angle, accuracy	Durability and accuracy are criteria, lack of definition or description of criteria
Criteria	Consistency, accuracy, mobility, simple, colorful	Lack of definition or description of constraints
Generate possible solutions	Diagrams of designs, catapults most common design, description of designs included, compressed air launcher and slingshot solutions	Descriptions lack depth, solutions should be name or identified in some way
Analysis	Students documented calculations	Failure to divide distance by 2, Corrections to original calculations
Optimization	Students completed a decision matrix	N/A
Decision	Provided best solution with a rationale, no single design was most common	Not all decisions included rationale, lacking in depth of decision explanation
Design specification	Diagrams included with a description, many solutions included a fixed 45-degree angle	N/A
Communicate design specs.	Description of the device, reference to stakeholders or people who would use the device	N/A

Engineering notebook rubric. The engineering notebook rubric was used to assess students' design challenge as well as their documentation. Results of rubric grading were analyzed by calculating the mean, median, mode, and standard deviation of each grading category as well as the grades overall. Figure 4.2.7 displays the increase I observed in the average grade in many selected notebook grading categories. The standard deviation for many of the grading categories was lower than in cycle 1 (seen Table 4.2.3). However, there were still areas in which students' documentation was lacking, such as problem definition, research, constraints, and criteria.

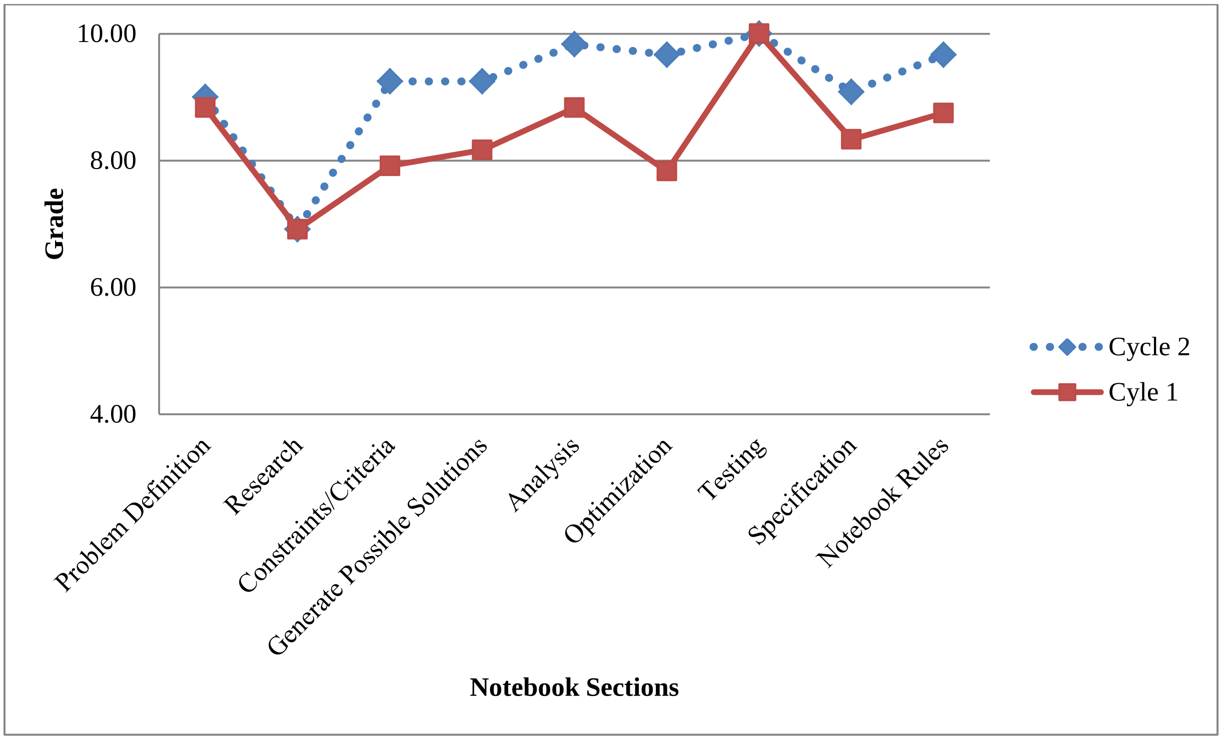

Figure 4.2.7: Chart of engineering notebook grades by category through two cycles.

The aforementioned lack of quality documentation is also evidenced by the standard deviation in each grading category. The earlier steps which saw poor documentation by most had a higher level of standard deviation. There were a few students who completed very thorough documentation and scored well, however most performed poorly in these areas. These areas were identified for improvement in the next cycle.

Table 4.2.3

Statistical Analysis by Category of the Engineering Design Notebook.

	Class average	Standard deviation	Mode	Median
Problem definition	9.00	6.92	10	10
Research	6.92	3.82	10	8.50
Constraints & criteria	9.25	1.54	10	10
Generate possible solutions	9.25	1.54	10	10
Analysis	9.83	0.58	10	10
Optimization	9.67	1.15	10	10
Testing	10	0	10	10
Specification	9.08	1.38	10	10
Notebook rules	9.67	0.89	10	10

Student interviews. Student interviews were recorded by students on their Chromebooks. Students then emailed the recording to the teacher who managed their identification numbers. This teacher then emailed me all the files which had identifying information removed. This process was cumbersome and some students had difficulty recording their interviews and getting them to the teacher.

All interviews were completed and the depth of the interview content from a number of students was more substantial than in the previous cycle. Since students recorded individual responses to questions, data is summarized by question and emergent theme (see Table 4.2.4).

Table 4.2.4

Interview Questions and their Related Themes

Question (summarized)	Themes
Describe the engineering design process.	Students understood and defined the concept, Attempting to find the best solution
Which steps of the engineering design process are scientific?	Analysis, Search, Identify the problem, The engineering design process is similar to the scientific method
What scientific concepts did you use in these steps? (from previous question)	Ballistic Trajectories, Calculations for launching the ball, Analysis and Optimization
Which steps of the engineering design process required math?	Analysis and Optimization
What mathematical concepts did you use in these steps (from the previous question)	Using ballistic trajectory calculations
What does optimization mean?	Finding the best solution
Describe what was hard and easy about optimization.	Hard: Weighting the criteria Easy: Filling out a decision matrix Most found process to be easy
What is analysis?	The use of math and science, students were confused / unsure
Described what was hard and easy about analysis	Easy: Math and calculations, Most students found easy Hard: Some found math and calculations difficult
What were helpful and hard parts of learning engineering design process?	Helpful: teacher examples, presentations and videos
Is there anything the teacher could have done better?	Need more time to practice calculations, need guidance on notebook documentation, many students replied no changes
How can you use what you learned in the real world?	Students explained practical applications and real-world scenarios, designing new technology, engineering

Triangulation. The convergence of analysis of each of the areas of instruction resulted in themes that emerged that may need to be addressed in the reflection stage of the cycle. As in Cycle 1, triangulation matrices were used to represent these convergent themes. The first of these matrices addresses a primary theme of the engineering notebook, a need for clearer expectations of documentation. While overall scores of the engineering notebook improved, there remained multiple areas where student documentation was lacking.

Table 4.2.5

Triangulation Matrix of Emergent Themes in the Engineering Notebook Activity

	Triangulated theme	Themes by data type		
		Observations / Field Notes	Engineering Notebook	Student Interviews
1	Students unclear on how to document some steps	Students asked multiple questions about how to document steps throughout the design challenge.	Scores were low in multiple areas	Students expressed confusion and need for direction.

There were some themes which emerged from the teaching of the engineering design process (see Table 4.2.6). The primary theme that emerged was student confusion regarding the search, constraints and criteria steps. In search, students were unclear how to define the problem space and what other activities should be included in the search step. Students also struggled with how to discern whether desired solution features were constraints or criteria. A secondary theme was the students’ difficulty in identifying the scientific concepts from the engineering design process. This was characterized by variation in student responses to the interview question addressing this concept.

Table 4.2.6

Triangulation Matrix of Emergent Themes in the Engineering Design Process Activity

	Triangulated themes	Themes by data type		
		Observations / Field notes	Engineering notebook	Student interviews
1	Spend more time on search step	Students asked multiple questions about how to document steps throughout the design challenge.	Search was lowest scoring area in engineering notebook grading.	No data
2	Improve examples and definitions of constraints and criteria	Students asked multiple questions about these steps and seemed confused.	Lack of detail in notebooks and recording of constraints as criteria and vice-versa.	No data
3	Presentation slide describing scientific concepts	There is not a specific slide or point at which the scientific concepts taught in the process are addressed	No data	Students have a diverse range of answers and some expressed confusion.

The primary theme of the ballistic trajectories activity recurred from Cycle 1. Multiple students forgot to divide their distance in half to find the midpoint of the parabola, which is the correct distance from the target. Additionally, during these calculations, the students experienced difficulty remembering how to convert the calculated launch velocity to a programmable power setting. This was not practiced during the ballistics presentation but was required during the engineering design challenge.

Table 4.2.7

Triangulation Matrix of Emergent Themes in the Ballistic Trajectories Activity

	Triangulated themes	Themes by data type		
		Observations / Field notes	Engineering notebook	Student interviews
1	Correct calculations slide to include division by 2 and typed formulas	Multiple students had to correct their calculations to divide distance by 2 before correctly launching the ball.	Students consistently forgot to divide the distance by 2	No data
2	Practice converting velocity to power setting for program	Multiple students forgot to do this step or did not complete the step before programming.	Students did not document this conversion in their notebooks.	No data

The design challenge also generated themes. While documentation of the engineering design process occurs during this activity, themes surrounding documentation were included in the engineering notebook activity. Two minor themes (see Table 4.2.7) emerged from the design challenge activity. The first overlapped with the theme from the ballistic trajectories activity, that students needed more time and practice completing calculations. The second theme was directed at practice and ensuring accuracy of the prototype (see Table 4.2.8).

Table 4.2.8

Triangulation Matrix of Emergent Themes in the Design Challenge Activity

	Triangulated themes	Themes by data type		
		Observations / Field notes	Engineering notebook	Student interviews
1	Walk through process and calculations before students document	Students had multiple questions about calculations during this activity.	Errors in dividing the distance by 2	Students recommended practicing the calculations more
2	Use ruler or square to set correct distance from target	Corrected accuracy issues with prototype.	No data	No data

While fewer themes emerged than the previous cycle, there were still problems.

Reflect

Application of the triangulation protocol resulted in a number of emergent themes to address in the next cycle. I explained my reaction to each of the major themes that emerged.

In addition to the themes and suggested changes developed through the emergent themes from the second cycle, there are some data collection procedure problems that needed to be addressed. The first is that the recording of interviews continued to provide problems for students. Some did not know how to record videos using their computer or personal devices, which caused significant difficulties in getting all interviews. Therefore, student interviews were recorded by another teacher in my department, who was also on the validation committee, using an audio recording system the belonging to the school. This ensured that all recordings were made and still remained anonymous.

The second data collection modification involved the tracking of duration that students spent on steps. Duration was recorded for students as they progressed from one step to the next but there was not a set time for each category. This doesn't provide specific enough data for developing a lesson plan with recommended timing for each step. Therefore, for the third cycle, I decided to run a timer and had a grid of the steps with each student's name. As students raised their hand and let me know that they have completed a step, I recorded their time. This allowed me to better understand the specific duration of each step which can be included in a lesson plan as recommended times for each of the steps. This data was then categorized by short, medium, and long durations for comparison to data from previous cycles.

Student responses to the questions regarding which step(s) of the engineering design process are scientific have been varied. While there was a question which addressed the scientific concepts learned, I was concerned that it lacked clarity for the students. Therefore, a modification was made to the student interview. A question was added that asked students which concepts they learned were scientific throughout the entire process. This clarified that students should consider all aspects of the lesson, not just the engineering design process, which was the perceived concern.

Engineering notebook changes and reflection. The primary theme that emerged from the engineering notebook was that students were confused about how to adequately document the engineering design process. While the rubric provided some guidance, it did not provide detailed guidance for each step. To alleviate this confusion, I developed a guide that included the expectation from the rubric, key terms and definitions, examples of good and bad documentation, and items to include in the documentation of each step. This guide coincided with the steps of the engineering design process and served as a resource for students as they worked through the problem.

Engineering design process changes and reflection. Two major themes needed to be addressed in the engineering design process activity. The first was that students were unclear on what the search step entailed as well as how to properly identify constraints and criteria. This theme was addressed by the strategy of creating a student guide. The guide contained detail and clarification of these concepts. This, combined with an increase in the time and discussion spent on these steps, created more clarity.

The second theme was students' inability to identify scientific concepts in the engineering design process. This was addressed in two ways. The first was through the addition of an interview question designed to more specifically target students' understanding of scientific concepts. The second was to include a slide in the presentation that summarized the scientific concepts learned and how they related to the engineering design process. These two components assisted students in identifying scientific concepts both in the presentation and at the conclusion of the unit.

Ballistic trajectories changes and reflection. The presentation previously eliminated a number of the issues and concerns that were expressed. However, the theme of incorrect distance calculations arose again this cycle. While students performed all the steps up to the distance calculations correctly, they still forgot to divide the distance in half. Therefore, more time was spent on the calculations. Additionally, the slide was revised to include division by 2 in the steps so that students were reminded visually as well as in practice.

Design challenge changes and reflection. The primary theme of the design challenge echoed the concern of correct calculations from the ballistic trajectories activity. Students also expressed concerns and confusion about proper documentation which was addressed in the engineering notebook changes and reflection. Each of these themes has already been addressed and therefore no further changes are necessary.

Validation group. The group concurred with all the changes from my reflection except for one. While I wanted to add a step to the presentation that reminded students to divide the distance by 2, one member of the committee explained that this change should not be included since the engineering design process often resulted in setbacks and errors that need to be corrected in order a design. Additionally, since many of the students forgot this step, it could be a teachable moment by allowing the students to make the error on the first attempt and having them reflect upon and correct their error. The remainder of the committee agreed that, while this step would be taught and the students would properly walk through the complete calculation, that this would challenge their recall and force them to more fully understand the calculations and how they are represented in the physical world. Based on the committee’s recommendation, I did not make the change to the slide. This was also included as part of the lesson plan to explain to the teacher how to work with the students to understand and correct this error.

During the meeting, a panel member suggested that the students be required to fill out the table of velocities themselves through the use of a photogate. However, the panel determined that this was not a critical part of the unit. The reasoning was that this unit is designed for a technology educator who is relatively unfamiliar with scientific concepts and may not have ready access to such scientific tools. Such an activity adds a level of complication and time that may overwhelm or add too much difficulty to the teacher. Therefore this was not implemented in Cycle 3.

Cycle 3

Plan

The second cycle completed near the end of the fall semester and, therefore, I was able to spend two weeks making changes recommended from Cycle 2. The most time consuming change was creating the student guide for the engineering design process documentation. Once the spring semester began, I met with new students’ parents and had them complete the required research explanation as well as obtained permission from both students and parents before beginning the third cycle.

Act

Upon completing these changes, I began teaching the new class of students. We covered topics in the same manner as before with the updated presentations and strategies. While the first cycle took five class periods to complete that were approximately 90 minutes each, the second cycle took seven class periods of a similar duration. Table 4.3.1 shows the time spent in each section when compared with Cycle 1.

Table 4.3.1

Time Spent in Instructional Activities in Minutes

Step	Cycle 1	Cycle 2	Cycle 3
Introduce engineering notebook	25	45	30
Present engineering design process	70	135	147
Launch water balloons	20	45	45
Football JUGS launching	30	30	25
Student reflection/ Ballistics presentation	110	105	70
Engineering design challenge	110	200	195
Total Time Spent	365	560	512

The amount of time spent in Cycle 3 on instructional activities was similar to that of Cycle 2. The ballistic trajectories presentation took less time because students asked fewer questions. The time spent on the engineering design challenge was similar to that of Cycle 2; however, the documentation was more robust, which indicates that the use of the documentation guide was more efficient in helping students through the process.

Develop

Observational data and field notes. Observational data in the form of duration and field notes were collected and analyzed in the same manner as preceding cycles. Frequency was not recorded. The coding scheme that emerged from my reading and understanding of the field notes resulted in four major themes.

- The engineering design process
- Ballistic trajectories
- Student reactions
- Teacher practices

The inductive analysis performed on the themes of the engineering design process and student reactions yielded similarities and differences from last cycle. Overall, the theme of understanding was prevalent in nearly every step of the engineering design process. There was still some confusion regarding constraints and criteria. While some students were able to identify these components correctly, others were unable to. Additionally, the documentation guide that was implemented this cycle was implemented and proved helpful to both the students and the teacher.

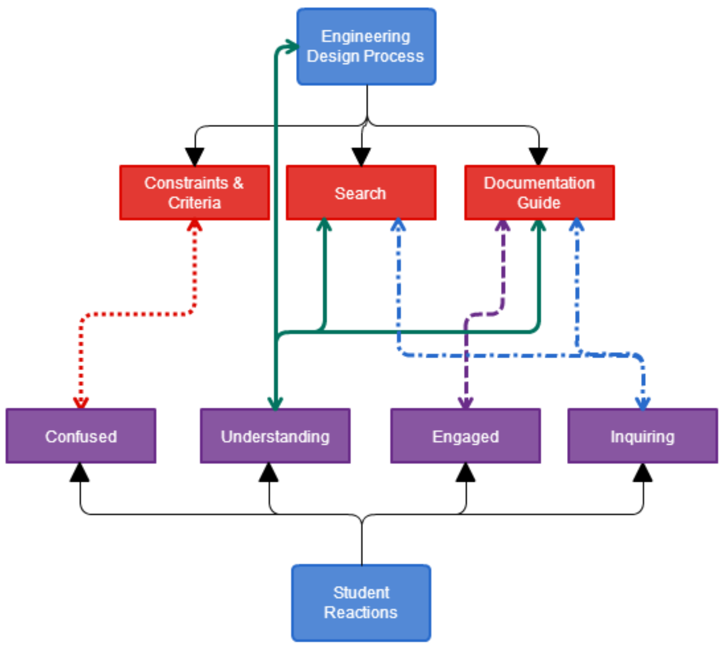

Figure 4.3.1. An inductive analysis of student reactions to the engineering design process.

The number of themes further decreased from Cycle 2 to Cycle 3 for teacher practice and the engineering design process. The only strong theme was that corrections or changes need to be made to how constraints and criteria are presented since there was still confusion.

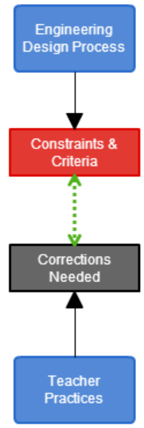

Figure 4.3.2. An inductive analysis of teacher practices to the engineering design process.

The ballistic trajectories and student reaction theme interaction simplified dramatically from last cycle. The primary concept that emerged was that of understanding. Students seemed to better understand the terminology and calculations. The issue with division of the distance in half also was no longer an issue. The students decided to call this step finding the midpoint and all were able to do so correctly.

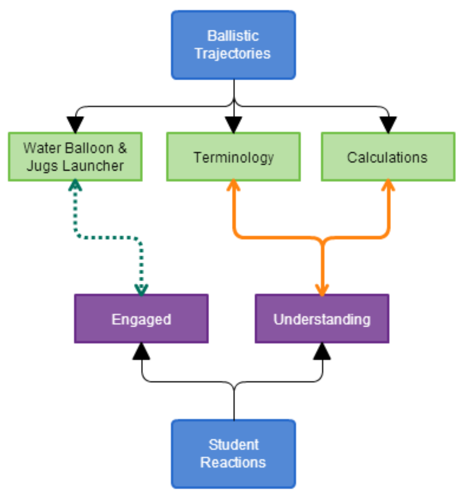

Figure 4.3.3. An inductive analysis of student reactions to ballistic trajectories.

There were no emergent themes for teacher practices for ballistic trajectories. The students were able to perform all calculations correctly and were engaged and enjoyed the process. The amount of practice time for calculations was increased as recommended in Cycle 2, which helped with student understanding of the correct procedure.

To track duration, I performed the same process as in previous cycles by having students raise their hand and state the step they were on when they were moving from one to the next. I also took the specific time it took each student to complete the steps as recommended in Cycle 2. The average of the time spent on each step as well as the duration of short, medium, and long can be seen in Figure 4.3.4 and Table 4.3.2.

Table 4.3.2

Time Spent by Students on each of the Engineering Design Process Steps

Step	Mean Time	Standard Deviation
Identify the need	3 min 30 sec	1 min 26 sec
Define the problem	3 min 35 sec	1 min 24 sec
Search	25 min 06 sec	13 min 28 sec
Define constraints	7 min 11 sec	3 min 13 sec
Define criteria	7 min 23 sec	6 min 18 sec
Generate alternative solutions	16 min 03 sec	12 min 45 sec
Analysis	33 min 56 sec	18 min 12 sec
Decision	16 min 24 sec	10 min 28 sec
Design specification	18 min 34 sec	10 min 21 sec
Communicate design specification	15 min 43 sec	20 min 06 sec

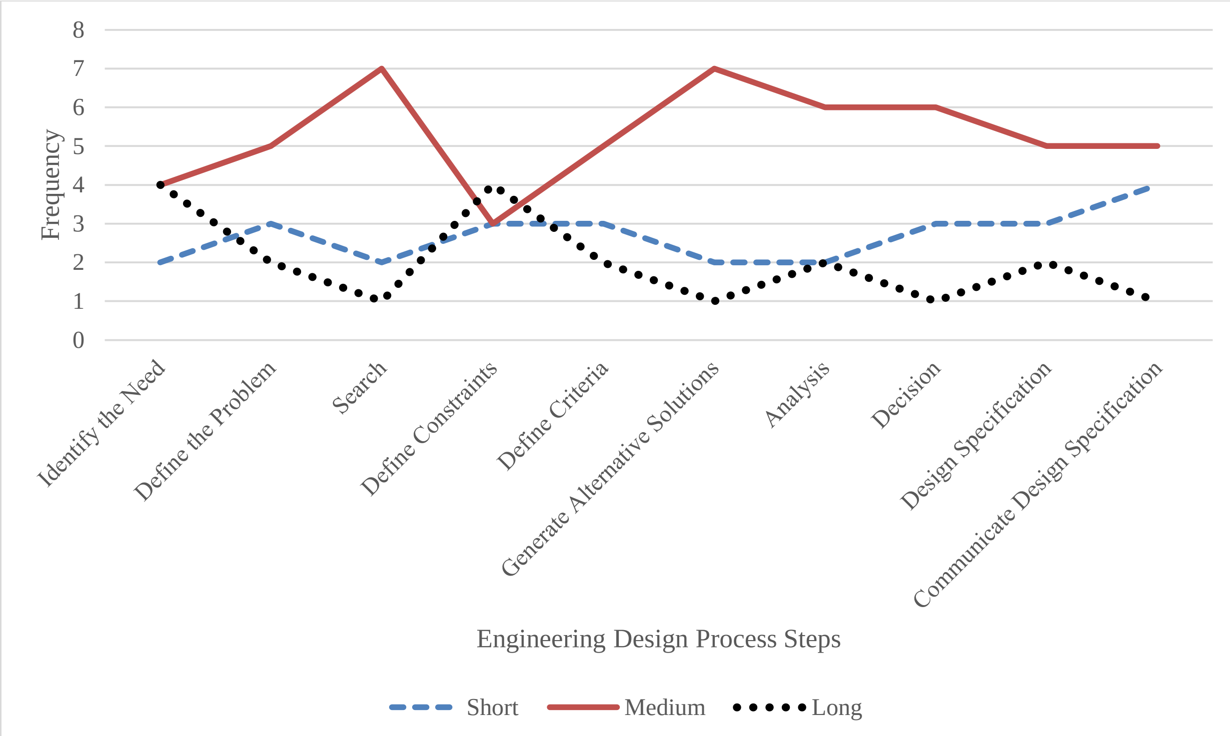

Figure 4.3.4. Time spent by duration on each of the engineering design process steps.

Student engineering notebooks. Open coding was used to analyze engineering notebooks. Those themes which appeared in the students' writing appear in the themes column while themes that were not included but were expected appear in the missing themes column. In Table 4.3.3, each step and its themes are described.

Table 4.3.3

Themes by Step of the Engineering Design Process

Step	Themes	Missing themes
Identify need	Identified stakeholders, identified the need	N/A
Define problem	Complete problem statement, Dude Perfect as stakeholders, statement of importance	N/A
Search	List of keywords, search questions made, example solutions given, patent searches made	Depth of documentation
Constraints	Size, cost, safety, distance	Diverse range of answers, some answers not constraints

Step	Themes	Missing themes
Criteria	Consistency, accuracy, mobility, simple, colorful	Some criteria mentioned are not criteria
Generate possible solutions	Diagrams of designs, designs named, description of designs, compressed air launcher and slingshot solutions most common	N/A
Analysis	Students documented calculations	N/A
Optimization	Students completed a decision matrix	N/A
Decision	Provided best solution with a rationale, referenced criteria in decision, compressed air and catapult most common	N/A
Design specification	Diagrams included with a complete and thorough design specification	N/A
Communicate design specs.	Description of the device, reference to stakeholders or people who would use the device	N/A

Engineering notebook rubric. The engineering notebook rubric was used to assess students' design challenge as well as their documentation. Results of rubric grading were analyzed by calculating the mean, median, mode, and standard deviation of each grading category as well as the grades overall. As is demonstrated in Figure 4.3.5, there was an increase in the average grade over many of the notebook grading categories. Additionally, Table 4.3.4 demonstrates that the standard deviation for many of the grading categories was lower than in previous cycles.

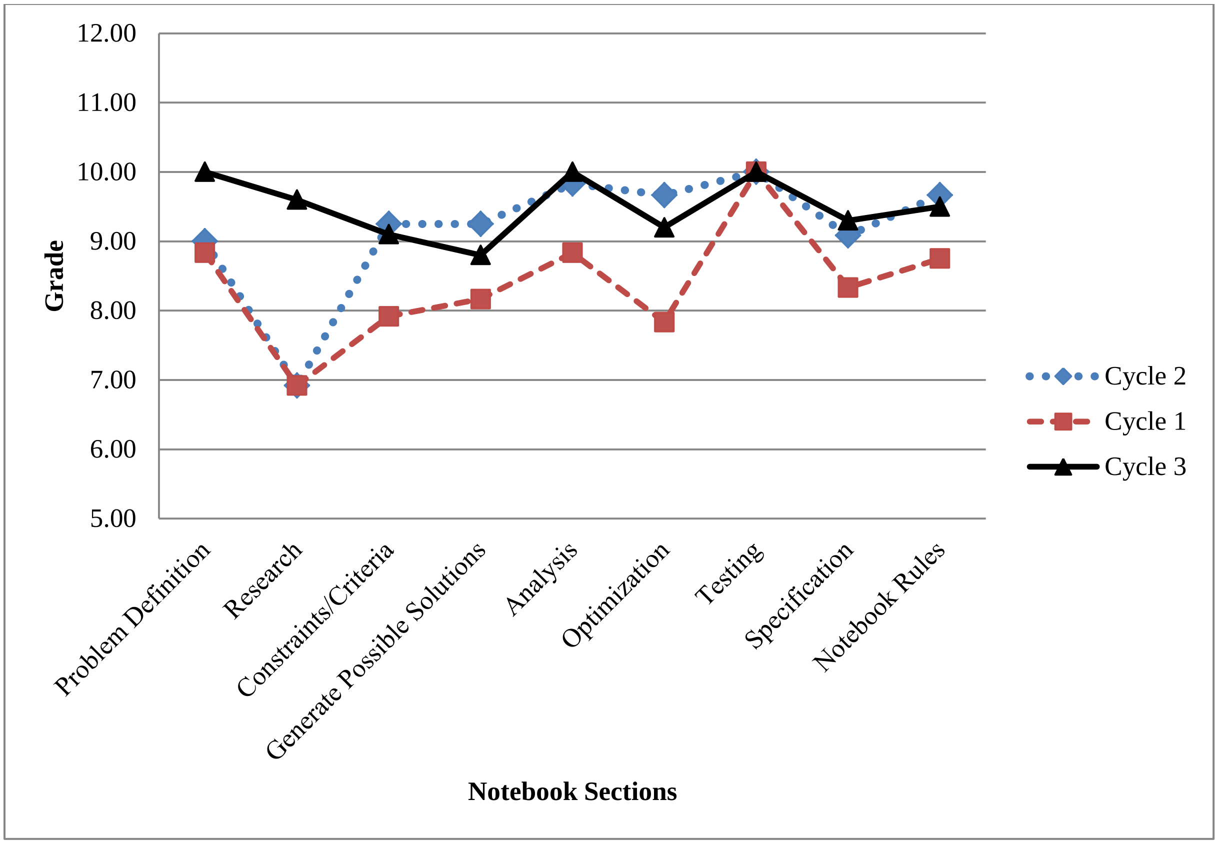

Figure 4.3.5. Chart of engineering notebook grades by category through two cycles.

The quality of documentation improved from Cycle 2 to Cycle 3 as evidenced by Figure 4.3.5 and Table 4.3.4. It was also obvious from the structure and quality of student responses that the documentation guide was utilized by nearly all students.

Table 4.3.4

Statistical Analysis by Category of the Engineering Design Notebook.

	Class average	Standard deviation	Mode	Median
Problem definition	10.00	0.00	10.00	10.00
Research	9.60	0.70	10.00	10.00
Constraints & criteria	9.10	1.20	10.00	9.50
Generate possible solutions	8.80	1.48	10.00	9.50
Analysis	10.00	0.00	10.00	10.00
Optimization	9.20	1.48	10.00	10.00
Testing	10.00	0.00	10.00	10.00
Specification	9.30	0.82	10.00	9.50
Notebook rules	9.50	0.85	10.00	10.00

Student interviews. Student interviews were recorded by a member of the validation group on a digital recorder. These files were then transcribed using an outside service. No identifying names or information were included in the recordings. The interviews were on average shorter than Cycle 2 but longer than Cycle 1. A thematic analysis was performed as in previous cycles (see Table 4.3.5).

Table 4.3.5

Interview Questions and their Related Themes

Question (summarized)	Themes
Describe the engineering design process.	Students understood and defined the concept, described as a problem solving process, attempting to find the best solution.
Which steps of the engineering design process are scientific?	Ballistic trajectories as part of analysis, the engineering design process as a whole, similar to scientific method.
What scientific concepts did you use in these steps? (from previous question)	Ballistic Trajectories, scientific observation.
Which steps of the engineering design process required math?	Analysis.
What mathematical concepts did you use in these steps (from the previous question)	Using ballistic trajectory calculations.
What does optimization mean?	Finding the best solution.
Describe what was hard and easy about optimization.	Hard: Completing the decision matrix. Easy: Choosing the best solution.
What is analysis?	Using calculations to predict/determine how solutions will perform.
Described what was hard and easy about analysis	Easy: Math and calculations.
What were helpful and hard parts of learning engineering design process?	Helpful: documentation guide, some also said presentations and other resources.
Is there anything the teacher could have done better?	No changes.
How can you use what you learned in the real world?	Students explained practical applications and real-world scenarios, engineering.

Triangulation. The convergence of analysis of each of the areas of instruction resulted in themes which emerged that may need to be addressed in the reflection stage of the cycle. As in previous cycles, triangulation matrices were used to represent these convergent themes. The first of these matrices addresses the primary theme of the engineering notebook, the improvement of documentation that resulted from students' use of the documentation guide. The overall grades and quality of student documentation improved, however, there was still some confusion regarding the proper documentation of the search step.

Table 4.3.6

Triangulation Matrix of Emergent Themes in the Engineering Notebook Activity

	Triangulated theme	Themes by data type		
		Observations / Field Notes	Engineering Notebook	Student Interviews
1	Documentation guide improved student performance.	Students used the guide in documentation.	Scores and quality of documentation improved.	Students said that guide was helpful.
2	Search step of documentation guide needs improvement.	Students still had multiple questions and confusion about search documentation.	Search documentation was weaker than other steps and needed more depth.	Students described search step as difficult.

The primary theme that emerged from the engineering design process was student confusion regarding the identification of constraints and criteria. Some students struggled with how to discern whether solution properties were constraints or criteria.

Table 4.3.7

Triangulation Matrix of Emergent Themes in the Engineering Design Process Activity

	Triangulated themes	Themes by data type		
		Observations / Field Notes	Engineering Notebook	Student Interviews
1	Improve examples and definitions of constraints and criteria.	Students asked multiple questions about the difference between constraints and criteria.	Some students listed constraints as criteria and vice-versa, diverse responses for identifying constraints.	No data.

The only theme to arise from the ballistic trajectories activity was students' desire to call the dividing of the change in distance by 2 finding the midpoint. Most of the students were familiar with this term and recommended it as a logical name for this part of the calculations. This also helped students to remember division by 2 which caused issues in previous cycles.

Table 4.3.8

Triangulation Matrix of Emergent Themes in the Ballistic Trajectories Activity

	Triangulated themes	Themes by data type		
		Observations / Field Notes	Engineering Notebook	Student Interviews
1	Use the term midpoint to represent the distance from target	Students liked this term and were able to relate it to the visual representation of a trajectory.	Students referenced the term in their calculations.	Students mentioned the term when discussing mathematic principles and understood it meaning.

The design challenge yielded no major themes other than students' understanding of the process and its completion.

Reflect

The application of the triangulation protocol resulted in emergent themes which were addressed. I explained my reaction to each of the major themes that emerged from the analysis. In Cycle 2, I recommended the implementation of some new data collection procedures. The first was in regards to student interviews. Student responses were recorded by another teacher in a separate room. This saved both time and effort for me and the students. The second change was to collect times during the design challenge activity. I was able to collect all student times and obtain a better picture of the time needed for students to complete each step. This information was useful in the development of lesson plan timing. The third and final change was to add a question to the interview regarding the scientific concepts. Students correctly identified scientific concepts in the original question. Most students repeated their answer from this previous question. Therefore, the original question did not seem to cause a problem with student identification of scientific concepts.

Engineering notebook changes and reflection. The primary theme which emerged from the engineering notebook was that students found the documentation guide helpful and that the quality of documentation improved. While the guide was useful, there was still some confusion on how to properly document the search step. Therefore, more time could be spent on walking student through the guide and example documentation.

Engineering design process changes and reflection. The only major theme which emerged from the engineering design process activity was the confusion that some students expressed when attempting to identify constraints and criteria. While many students were able to correctly identify these characteristics, there was some confusion as to whether they should be considered constraints or criteria. To clarify these concepts, I included in their presentation the definition and examples of these concepts from the International Technology and Engineering Education Association (ITEEA) *Standards for Technology Literacy* (International Technology Education Association, 2007) as well as NASA’s *Packing Up for the Moon Educator Guide* (Johnson, 2007).

Ballistic trajectories changes and reflection. While teaching the calculation of trajectories, students identified division by 2 as locating the midpoint. This was a term they were understood from math class and it helped them in performing the appropriate calculations.

Therefore, the step of dividing the distance by 2 was renamed calculating the midpoint in the ballistic trajectories presentation.

Design challenge changes and reflection. There were no emergent themes except for the confusion between constraints and criteria and the further explanation of the search step. Overall, students demonstrated understanding of the challenge and successfully completed the process including correctly calculating and launching the ball through the target.

Validation group. The validation group meeting was shorter than previous meetings since there were fewer recommended changes than in previous cycles. We discussed the documentation steps and the group liked that students had to learn, make corrections, and document more thoroughly. I described a student having to go back and document prior steps in more detail because they realized more information was needed. The group described this as a sign of learning. The math and science teachers concurred that calling the step in which students divide the distance in half the midpoint was an accurate use of the term and were excited that students identified the term. The group discussed the broader practical application of the action research process and recommended that this be used to develop other units of instruction for this course. One member also recommended that a capstone or course-long project be incorporated into the course. The group discussed the merits of such a project and stated that if this were to be added, that some guidelines should be developed for the students and that approval before beginning should be provided by the teacher. There were no other comments or concerns.

CHAPTER 5 FINDINGS

The process of completing an action research study was an exceptional learning opportunity not only in conducting research, but also in becoming a better teacher. Throughout the process I learned a substantial amount about the topic I taught, data collection, and analysis. This information shaped my understanding of research questions for each cycle and the overall research question. As Herr and Anderson (2005) explained, there is no prescribed format for reporting findings for action research studies. However, they recommended that data collection, analysis, and reflection be reported separately from data that addressed specific research questions. Thus, specific changes are reported in context while broader, holistic questions are treated separately. In this chapter, I discuss findings by research question and how these findings changed from cycle to cycle.

Research Question 1

To what degree do students understand the elements of the engineering design process, ballistic trajectories, and the laws of conservation of energy?

Findings

By the conclusion of Cycle 3, Students were able to correctly identify and apply the elements of the engineering design process, demonstrating their mastery of the content. This was accomplished through students' documentation of their application of the engineering design process to a practical challenge of launching a golf ball through a target. Students were also able to correctly identify ballistic trajectory terminology, including the laws of conservation of energy. This was evidenced through discussion of terminology and correct calculation of trajectory values in the design challenge.

Cycle 1

Initially students were able to identify the steps of the engineering design process and provide adequate definitions; however, they lacked adequate documentation of the process. Their understanding was weak, and lacked full mastery of the content. Additionally, there was confusion regarding identification of constraints and criteria. For ballistic trajectories, students were able to identify key concepts such as velocity, distance, and height. They were also able to perform the required calculations and launch the ball through a target. However, there were some issues with calculating of trajectories correctly on the first attempt. While students understood some key scientific principles such as the laws of conservation of energy, there was significant confusion generated from videos and organization of content in the presentation of these ideas.

Cycle 2

Student strength of understanding improved from the previous cycle, however complete mastery of the content was not obtained. They were able to correctly identify the purpose and most components of the engineering design process. While there was still confusion regarding constraints and criteria, the primary area of concern was student lack of clarity when documenting the engineering design process. Updates to the presentation materials helped improve student understanding of the laws of conservation of energy and ballistics. However, there was still confusion when calculating distance from a target.

Cycle 3

The final cycle saw student mastery of the engineering design process through significant improvements in quality of documentation and application. All but two students were able to correctly identify constraints and criteria. Student understanding of ballistics and the laws of thermodynamics improved from the previous cycles as well. This improvement came in student's ability to understand the step of the ballistic calculations for calculating distance. Overall, the quality of teaching and learning of these concepts improved from cycle to cycle. However, there was one student who struggled to obtain mastery of the content. This individual became fixated on a solution and struggled with this systematic approach to problem solving. While not all students were able to completely master every aspect of the content taught, this does not constitute a failure of the process. Rather, as is discussed in later in this chapter, the continued improvement and future cycles of research can help to further improve and include those students who struggled with this lesson.

Research Question 2

How effective were instructional strategies in enhancing student understanding of relevant mathematical and scientific concepts?

Findings

Instructional strategies improved from cycle to cycle in quality, timing, organization, and teacher knowledge of resources. This improvement resulted in a demonstrable enhancement of student understanding of the concepts taught.

Cycle 1

While students were able to identify and apply some of the content taught, there were a number of issues with the organization, quality, and timing of instructional activities. Organization and quality of my presentations for the engineering design process and calculation of ballistic trajectories needed improvement as they caused confusion. Much of this confusion stemmed from videos that were included in the presentation but did not adequately address the concepts. Additionally, the timing of the outdoor activities rushed the presentation of the engineering design process causing confusion in identifying and applying this concept.

Cycle 2

Improvements made to instructional strategies generated improvement in students' ability to identify and apply the concepts taught. However, student documentation of the engineering design process, as well as incorrect distance calculations for ballistic trajectories, continued to surface. While the increased time and improved examples employed in presentation of the engineering design process and ballistic trajectories improved some students' understanding of the concepts, there were still incorrect calculations and a general lack of depth in documentation of the engineering design process.

Cycle 3

The final cycle demonstrated marked improvement in student understanding and application of the principles taught. Documentation improved with the use of a guide that was implemented and ballistic calculations were performed correctly. Students were even able to define a new term, the midpoint, for completing these calculations. These improvements came not only as a result of the improved resources and timing, but also with my confidence and experience in teaching the concepts for a third time.

Research Question 3

How do students explain the practical application of the content learned to their lives?

Findings

By the final cycle, students were able to describe the practical application of the engineering design process. They described its use in the engineering profession, in solving local, personal problems, and its application to global needs.

Cycle 1

While practical application of content was discussed, students were unable to identify any external practical application of the concepts learned. They were only able to identify the utility of what was learned in reference to the problem itself. Therefore, significant changes to teaching strategies and resources were made.

Cycle 2

Changes in teacher strategy and resources resulted in significant improvement over the previous cycle. Nearly every student explained that the engineering design process can be applied to solving practical issues in their lives and the lives of others. This occurred through discussion during activities and in interviews. During such discussion, an example of practical application was provided by a student when they described straws which filter water as you drink with them. They identified this as a solution to a lack of potable water in developing countries. This was one of many examples that demonstrated students' ability to identify practical applications of content learned.

Cycle 3

Students in Cycle 3 were able to identify practical applications of concepts learned. Additionally, students demonstrated understanding that the engineering design process can be used for all types of problems, not just those that would be considered engineering issues. The ability to identify the practical application of concepts learned took a substantial leap in the second cycle and was then consistent in Cycle 3.

Overarching Research Question

In what ways can I improve my practice of teaching the engineering design process through the application of the action research methodology?

The action research process is a unique means of conducting research as it provides an opportunity to create meaningful improvements over multiple iterations of a study (McKernan, 1996). In conducting this study, I was able to improve my instructional strategies three times, each rendering enhanced student learning. This improvement was evidenced in the organization of activities, enhanced discussion, and the incorporation of new resources. Additionally, through repetition, my knowledge of the content and comfort with its teaching increased dramatically. The improvement evidenced through the action research method in all aspects of instruction resulted in this study's resounding success. These improvements can be seen in four key areas of my practice.

- Resources: Resources were developed for the teaching of the course and were continuously improved from cycle to cycle. These resources included presentations for the engineering notebook, engineering design process, and ballistic trajectories. Also developed were an engineering notebook template, prototype launcher, and lesson plan. As the cycles progressed, another resource in the form of a documentation guide for the engineering design process was developed and improved. These, along with the examples and activities employed in the teaching of the aforementioned concepts experienced improvement.
- Organization: The order in which ideas and activities were presented improved and allowed for more effective teaching and management of the classroom.
- Timing: While there was variety in time spent each cycle, the amount spent within each instructional activity was used more efficiently and effectively.
- Knowledge: With each iteration, my understanding of and ability to teach the concepts improved.

Hine and Lavery (2014), through their study of multiple teachers implementing action research, determined that this method can be used to improve teacher practice. This assertion was also made by Mertler (2014), McNiff (2013), and other experts in action research. Danielson et al. (2009) explained that teacher practice involves four general areas: planning and preparation, the classroom environment, instruction, and professional responsibilities. Within these general areas lie activities that tie directly to the aforementioned areas: demonstrating knowledge of resources (knowledge), designing coherent instruction (resources), and managing classroom procedures (organization, timing). Therefore, the improvement of teacher practice was evidenced by the improvement made in the aforementioned areas.

Contribution to Literature

Mertler (2014) described a gap between research and application. He explained that quality action research bridges such a gap through sharing results. This provides other "teacher-researcher[s] with the opportunity to gain additional insight into the topic under investigation as well as into the research process itself" (p. 272). Therefore, this dissertation contributes to literature through its exposure of the validity of the action research methodology as a bridge between research and practice. Additionally, it provides a means for other teachers and researchers to better understand the implementation of the engineering design process and STEM (Science, Technology, Engineering, and Math) concepts in the technology education classroom. While results cannot be generalized, they do have value and contribute to literature.

Mertler (2014) explained that "the overarching goal of action research is to improve practice immediately within one or a few classrooms or schools" (p. 39). In order to improve my practice, I introduced engineering to my technology education classroom. As explained by Asunda and Hill (2007), the engineering design process is a starting point for teaching engineering to students. While a call was made for teachers to incorporate engineering into technology education classrooms (Kelley, 2010c), there are few resources for technology educators to do so (Asunda & Hill, 2008). What resources are available lack the mathematical and scientific concepts of predictive analysis and optimization, which complete and enhance the robustness of the engineering design process (Kelley, Brenner, & Pieper, 2010). The unit of instruction developed through this research is designed for technology educators, who may lack experience teaching STEM concepts. It also incorporates the principles of predictive analysis and optimization in a manner that is both simple yet robust enough to meet national science and math standards (NGSS Lead States, 2013). Aligning with Mertler's (2014) contribution to literature expectations, this study adds to our understanding of teaching engineering and technology and enhances the validity of action research as a methodology. He also explained that action research provides a valid contribution to literature when performed with rigor and shared with others. I plan on publishing this dissertation and articles related to what I learned and experienced and presenting my findings to teachers and researchers. Since the study also met the components of rigor, it provides a valid contribution to literature as well as engineering and technology education.

Recommendations for Future Research

This study provided a starting point for incorporating engineering into my classroom. Yet it represents one of many possible topics and professional applications that could be included in an introduction to engineering course. The Georgia Department of Education (2013) described a number of pathways or program choices that involve engineering for high school students. The first of these, called "Foundations of Engineering and Technology" explicitly states areas of engineering to which students should be exposed.

> STEM-FET-2: Develop an understanding of engineering and technology and describe the principal fields of engineering specializations (ex. aeronautical, automotive, chemical, civil, industrial, mechanical, computer software, electrical, and biomedical) and identify associated career tracks (Georgia Department of Education, 2013)

As part of Career, Technical, and Agricultural Education (CTAE) in Georgia, this course provides guidelines for course content. The University of Texas has also developed curricula for engineering courses that include diverse areas of engineering. Next Generation Science Standards and the Standards for Technological Literacy (International Technology Education Association, 2007) also embrace introduction of various areas of engineering as an important concept within the framework of STEM education (NGSS Lead States, 2013). Yet these programs do not provide resources for instruction by technology teachers. As Kelley et al. (2010) expounded, there is need for resources like those developed in this study for technology educators. Therefore, I recommend that I continue to conduct action research studies implementing the numerous fields of engineering. This will allow me to continue development of resources to meet the curricular requirements of my introductory engineering course. As described in the contribution to literature, the resources I have and will develop can also provide insight for engineering and technology educators as they develop and improve their own courses and research.

Both action research and engineering design are creative processes that seek to solve a problem by generating an optimal solution. They are also both iterative in nature. These commonalities make action research a uniquely suited tool for continued improvement of my practice through new units of instruction in engineering. However, the utility of action research as a methodology extends beyond engineering and technology education. McKernan (1996) explained that all teachers can take advantage of the improvements to curricula which come about through the application of action research. McNiff (2013) concurred that action research can provide significant improvements to teacher practice. Through this study, I have experienced the improvements in curriculum and practice that were promised by these and other action researchers. Mertler (2014) explained that experiences such as mine, when published, add to the greater validity and legitimacy of the action research methodology. Therefore, I recommend that other teachers and researchers employ the action research methodology to improve their practice and experience the many benefits it imparts.

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APPENDIX A

IRB Forms, Approval, and Parental Consent

There are a total of three forms that will be presented to the parents and students involved in the study. The first is a general consent form which contains pertinent information about the study, its risks and benefits, etc… The second is the parent consent form which will be signed to allow student participation. Students will also have the right to consent, so the last form is the student consent form. If either the student or the parent refuse consent, then they will be exempt from the study. Each form begins on its own page.

The University of Georgia

Phone 706-542-3199

Office of the Vice President for Research
Institutional Review Board

Fax 706-542-3660

APPROVAL OF PROTOCOL

September 22, 2015

Dear Jay Rojewski:

On 9/22/2015, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	An Action Research Study of Implementing Engineering Design in the Technology Education Classroom
Investigator:	Jay Rojewski
IRB ID:	STUDY00002540
Funding:	None
Grant ID:	None

The IRB approved the protocol from 9/22/2015.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103).

Sincerely,

Adam Goodie, Ph.D.
University of Georgia
Institutional Review Board Chairperson

UNIVERSITY OF GEORGIA
CONSENT FORM
An Action Research Study of Implementing Engineering Design in the Technology Education Classroom

Researcher's Statement
I am asking your child to take part in a research study. Before you decide to allow your child to participate in this study, it is important that you understand why the research is being done and what it will involve. This form is designed to give you the information about the study so you can decide whether to allow your student to be in the study or not. Please take the time to read the following information carefully. Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, you can decide if you want your child to be in the study or not. This process is called "informed consent." A copy of this form will be given to you.

Principal Investigator: Kristopher Brent Hollers
Business and Technology Education Department
Email: bhollers@btcatholic.org Phone: 404-227-1778

Purpose of the Study
As a natural part of their practice, teachers update and improve their curriculum to provide a better educational experience for their students. When this process is performed by a teacher who is also a researcher, it is called Action Research. The research that your child would participate in, should you choose to allow them, would involve me as a teacher researching how to improve the robotics class in which they are currently enrolled. The suggested improvement is to include a problem solving process known as the Engineering Design process to the class curriculum. The Engineering Design process is useful because it teaches problem solving skills to students and requires them to use math and science to solve these problems. Throughout the process of including this Engineering Design process in the course, I will observe how the students understand the concepts being taught as well as seek feedback from the students themselves through having them respond to questions about the content they learned. Additionally, I will use proven grading rubrics to assess the students' work that they complete through learning the Engineering Design process. By gathering this information, I will be able to make informed decisions as to how to continue to improve my instruction as a teacher. This is why the study will be an Action Research study as mentioned earlier.

Study Procedures
If you agree to allow your child to participate, they will be asked to …

- Provide confidential feedback to the teacher about the effectiveness of the instruction.
    - The providing of feedback by the students will be completed at home through the use of a call-in voice mail service (Google Voice). This should take the student approximately 30 minutes to an hour.
    - The student feedback mentioned in the previous bullet will include questions such as the student's understanding of specific content or steps, the effectiveness of the teaching style and content, and areas which the student encountered difficulty.

- This feedback will be an audio recording which will be completed through an online voice mail service (Google Voice) which will then be translated into text before being permanently deleted.

Risks and discomforts

- I do not anticipate any risks from participating in this research as it will be conducted as a normal part of teaching and improving the course.

Benefits

- Students may obtain a better understanding of the engineering design process as well as how to solve challenging or difficult problems.
- Students may better understand how to apply math and science to producing the best possible solution for a problem.
- Students may be able to better define and express problems and their solutions to their peers.
- Better understanding of how to implement the teaching of the engineering design process as well as how students understand and apply the process may occur which could contribute to improving this and other technology and engineering courses.

Alternatives

The study will be performed and implemented as part of the normal classroom experience. Therefore, students will be asked to complete the related assignments and to understand the content taught. If a parent or student decides that they do not wish to be included in the research, their evaluations, observations, and interviews will be removed from the information gathered and the student will not be penalized for withdrawing from the research.

Incentives for participation

There are no incentives for participation and the student's grade will not be helped nor hindered for their participation or lack thereof.

Audio/Video Recording

There will be one audio recording of each student participating in the study. This recording will be of the student answering questions regarding the effectiveness and usefulness of the teaching that occurred. They will provide this recording at home by calling a phone number provided by the teacher. This phone number is part of a service called Google Voice which is an online voice mail system that allows individuals to call and leave messages. When they call this phone number, they will be taken to a voice recording with instructions on how to proceed. The student will then be recorded answering the questions provided by the teacher. These responses are saved by the system and will then be analyzed by the teacher. Prior to beginning the research, each student will be given a randomly assigned number. They will use this number to identify themselves when answering the questions when they call the phone number. The master list of student names and numbers will be kept by another teacher within the department who will check to make sure that all students called and answered the questions. The teacher of the course (myself) will never have access to this list and once all students have recorded their responses, the list will be destroyed. Once all student responses are collected, they will be converted to text and then the original files from the Google Voice service will be permanently deleted. The

Google Voice service is encrypted and secured with a password. Additionally, since no identifying information of the student is collected, their responses will be confidential.

Privacy/Confidentiality
Any information collected from students will be identified through the use of randomly assigned codes as explained in the audio/video recording section above. These codes will be randomly generated and assigned by another teacher in the department and will kept on a sheet of paper in a locked filing cabinet only accessible to this teacher. The researcher/teacher of this course will never have access to this file and it will be destroyed once all student data is collected. Any observations made by the teacher of students that are written will not contain identifying information. These steps will help ensure the confidentiality of the student data.

Researchers will not release identifiable results of the study to anyone other than individuals working on the project without your written consent unless required by law.

Taking part is voluntary
Your student's involvement is voluntary, you or your student may refuse to participate before the study begins, and discontinue at any time, with no penalty or loss of benefits to which he/she is otherwise entitled. If you decide to withdraw from the study, the information that can be identified as yours will be kept as part of the study and may continue to be analyzed, unless you make a written request to remove, return, or destroy the information.

If you have any questions or concerns regarding your child's rights as a research participant in this study, you may contact the Institutional Review Board (IRB) Chairperson at 706.542.3199 or irb@uga.edu.

Research Subject's Consent to Participate in Research:
To voluntarily allow your child to take part in this study, you must sign the attached parental consent form. Your signature indicates that you are allowing your child to participate in this study.

Parental Permission Guidance

If you have any questions or concerns regarding your child's rights as a research participant in this study, you may contact the Institutional Review Board (IRB) Chairperson at 706.542.3199 or irb@uga.edu.

Research Subject's Consent to Participate in Research:

To voluntarily allow your child to take part in this study, you must sign on the line below. Your signature below indicates that you have read or had read to you this entire Parental Permission Form, and have had all of your questions answered.

Your Child's Name: ____________________________________

Your Signature: ____ Date ____________

Your Printed Name: ____________________________________

Signature of Researcher: ________________________________ Date ____________

Printed Name of Researcher: _____________________________

Please sign both copies, keep one and return one to the researcher.

Assent Script/Form for Participation in Research
An Action Research Study of Implementing Engineering Design in the Technology Education Classroom

We are doing a research study to find out how to properly teach the engineering design process and problem solving to students in high school technology classes. We are asking you to be in the study because you are in a technology class that is learning the engineering design process and problem solving. If you agree to be in the study, you will be taught the engineering design process and will learn to apply it in solving a problem over the course of around 2 weeks. You will also answer questions about what you learned. You will allow us to watch you and take notes while you are learning and working. Being in the study help you better understand how to solve problems and help you understand the engineering design process and its importance. You may also learn how to apply math and science concepts to solving a problem.

You do not have to say “yes” if you don’t want to. No one, including your parents, will be mad at you if you say “no” now or if you change your mind later. We have also asked your parent’s permission to do this. Even if your parent says “yes,” you can still say “no.” Remember, you can ask us to stop at any time. Your grades in school will not be affected whether you say “yes” or “no.”

Your responses to questions about what you learned and how you were taught will be anonymous so your teacher will not know what you said in your response. We will not use your name on any papers that we write about this project. We will only use a number so other people cannot tell who you are.

You can ask any questions that you have about this study. If you have a question later that you didn’t think of now, you can ask Mr. Hollers by emailing him at bhollers@btcatholic.org, calling him at 404-227-1778, or asking him in class.

Name of Child: ______________________________ **Parental Permission on File:** ☐Yes ☐No

(For Written Assent) **Signing here means that you have read this paper or had it read to you and that you are willing to be in this study. If you don’t want to be in the study, don’t sign.**

Signature of Child: ________________________________ **Date:** __________________

Signature of Researcher: ___________________________ **Date:** __________________

APPENDIX B

Data Collection Instruments and Details

The following instruments will be used throughout each of the action research cycles for the purpose of collecting data to be analyzed. The instruments are; an engineering design assessment rubric (Asunda & Hill, 2007), an engineering notebook assessment rubric (Kelley, 2014), an observation checklist, and an end of unit student survey.

Engineering Design Assessment Rubric

The rubric found on page 81 is an adapted version of Asunda and Hill's (2007) rubric which was developed based on the essential aspects of an engineering design activity. This rubric will serve as a summative assessment for the students. Slight adaptations were made to the headings and structure of the table to create an editable document more readily designed for grading the student projects. While these formatting changes were made, no changes were made to the actual wording, content, or grading scale associated with the rubric.

Engineering Notebook Assessment Rubric

The rubric found on page 83 is an adapted version of Kelley's (2014) engineering notebook rubric designed specifically to grade the engineering notebook which students will complete as a part of the engineering design process. Kelley (personal communication, July 17, 2015) approved of the use of this rubric for such a research activity and further emphasized that such an activity is a common practice of engineers and thus should be incorporated into any engineering design activity. The rubric has been adapted to fit in a word document and has been formatted to allow for the grading of student projects. While these formatting changes were made, no changes were made to the actual wording, content, or grading scale associated with the rubric.

Observation Checklist

The observation checklist was developed based on the activities which students should perform in the completion of an engineering design project (Eide, et al., 2002). In addition to the checklist are spaces for field notes to make this observational tool more semi-structured in nature (Mertler, 2014). This also allows for more depth in the observation while still determining if basic activities are being performed. The checklist component of this observation sheet may change based on data collected and analyzed from cycle to cycle to reflect common and important themes in the research.

Student Interview

The student interview will be completed at the end of each cycle. Students will call a google voice number with their unique identifier which will not be known to me, but to another teacher in the department who will keep track of the responses to ensure all students are completing the questionnaire for a participation grade. This will alleviate concerns of students with respect to their being critical of specific aspects of the coursework as their responses to the questions will be anonymous (Mills, 2003). Additionally, the questions are each related to the research questions established for this study as can be seen in the Table A1 below.

Table A1

Student Interview Questions and Related Research Question

Research Question	Interview Question	Rationale
To what degree do students understand the elements of the engineering design process, ballistic trajectories, and the laws of conservation of energy?	Explain in your own words, what is the engineering design process?	This will serve as a basis for the following questions. It requires them to recall the steps they learned to help them better answer the upcoming questions.
	Which step(s) of the engineering design process would you consider scientific?	Asks them about which science concepts they learned. I used the term idea because concept may be too complex a term for the students.
	Consider your response to the previous question. What scientific ideas did you learn or use in the step(s) you identified?	Follow-up question to clarify the previous information. Also may spur the student to recall other concepts or ideas they learned.
	Which step(s) of the engineering design process required math?	Asks them about which math concepts they learned. I used the term idea because concept may be too complex a term for the students.
	Consider your response to the previous question. What scientific ideas did you learn or use in the step(s) you identified?	Follow-up question to clarify the previous information. Also may spur the student to recall other concepts or ideas they learned.
How effective were instructional strategies in enhancing student understanding of relevant mathematical and scientific concepts?	One of the steps in the engineering design process was optimization. Can you explain what this term means?	Begins the recollection of the specific optimization step. Helps recall for future questions and sets the stage for follow-up questions.
	Consider your response to the previous question. What parts of this step did you find easy and which parts did you find difficult? Please explain why you feel this way.	Asks students to point out specific concepts they struggled with or found easy. This focuses on content primarily, future questions will focus on delivery.

Research Question	Interview Question	Rationale
	One of the steps in the engineering design process was analysis. Can you explain what this term means?	Begins the recollection of the specific analysis step. Helps recall for future questions and sets the stage for follow-up questions.
	Consider your response to the previous question. What parts of this step did you find easy and which parts did you find difficult? Please explain why you feel this way.	Asks students to point out specific concepts they struggled with or found easy. This focuses on content primarily, future questions will focus on delivery.
	Please attempt to remember learning the engineering design process. Are there any parts that you found helpful in learning this process? Were there any parts that you found made learning more difficult?	This will ask students to recall the teaching strategies used throughout the unit. Those activities which they found troubling as well as useful will provide a means for improving instruction.
	Consider all that you learned this unit. Is there anything that you feel the teacher could have done better to help you learn the content? (For example: More time, different examples, reviewing the content, etc…)	This will ask students more broadly anything that they found lacking in the instruction. This should show some overlap with the previous question and provide another perspective on the concepts students struggled with.
How do students explain the practical application of the content learned to their lives?	In your own words, describe how you could use what you have learned in the real world.	These questions are essentially the same. Students will also be asked to write their thoughts about this question in the engineering notebook.

STUDENT INTERVIEW

Students,

At the completion of the unit, you will be asked to answer the following questions. In order to do so, you will need to call the following phone number: xxx-xxx-xxxx. When you call, it will ask who is calling, please provide your randomly assigned number. You will then hear a voicemail message recorded by your teacher thanking you for completing the interview. You will then be instructed to provide your responses. Please say the question number followed by your response. Please respond completely to the question and provide as much detail and information possible, even if you think it may be irrelevant. You do not need to read the question itself. Once you have responded to all the questions simply hang up the phone and your responses will be recorded.

Please remember that your responses will be kept confidential and that they will be transcribed to a text format by someone other than your teacher so all your responses are anonymous. Once transcribed (converted from audio to text), the voicemails will be permanently erased. Please provide an honest response to the questions as the goal is help improve the teaching of the material. Thank you for taking the time to complete this interview.

Question Number	Question
1	Explain in your own words, what is the engineering design process?
2	Which step(s) of the engineering design process would you consider scientific?
3	Consider your response to the previous question. What scientific ideas did you learn or use in the step(s) you identified?
4	Which step(s) of the engineering design process required math?
5	Consider your response to the previous question. What scientific ideas did you learn or use in the step(s) you identified?
6	One of the steps in the engineering design process was optimization. Can you explain what this term means?
7	Consider your response to the previous question. What parts of this step did you find easy and which parts did you find difficult? Please explain why you feel this way.
8	One of the steps in the engineering design process was analysis. Can you explain what this term means?
9	Consider your response to the previous question. What parts of this step did you find easy and which parts did you find difficult? Please explain why you feel this way.
10	Please attempt to remember learning the engineering design process. Are there any parts that you found helpful in learning this process? Were there any parts that you found made learning more difficult?
11	Consider all that you learned this unit. Is there anything that you feel the teacher could have done better to help you learn the content? (For example: More time, different examples, reviewing the content, etc…)
12	In your own words, describe how you could use what you have learned in the real world.

ENGINEER'S NOTEBOOK RUBRIC

Performance Criteria	Attribute	Performance Level			Score
Design Process Stage		**Low= 1 (6 or below pts)**	**Medium = 2 (7 or 8 pts.)**	**High = 3 (9 or 10 pts.)**	
Problem Definition: The student will provide the identification of the need and rationale for the solution to a design problem.	Intensity (clarity and relevancy)	The notebook contains a design problem statement that requires further explanation of the problem and lacks strong rationale of the need and no credible sources are cited.	The notebook contains a design problem statement that provides a limited explanation of the problem but provides rationale of the need using limited credible sources.	The notebook contains a design problem statement that provides a clear explanation of the problem and provides in-depth rationale of the need with multiple credible sources cited.	
Brainstorming/ Idea Generation: The student will provide preliminary ideas to help solve the design problem.	Amount (breadth)	The notebook contains 15 or more preliminary design ideas to solve the problem. 2 ideas will be further explored through design sketches and detailed descriptions.	The notebook contains 35 or more preliminary design ideas to solve the problem. 5 ideas will be further explored through design sketches and detailed descriptions.	The notebook contains 50 or more preliminary design ideas to solve the problem. 10 ideas will be further explored through design sketches and detailed descriptions.	
Research: The student will conduct extensive research on the design problem and possible design solutions.	Amount (breadth)	The notebook contains little or no evidence of U.S. patent searches of existing solutions and little or no verifiable facts of the design problem and some industry standards presented for possible solutions. No evidence of focus group, interview, or interviews conducted. No details as to how and why the constraints and criteria were identified.	The notebook contains some evidence of U.S. patent searches of existing solutions and some verifiable facts of the design problem and some industry standards presented for possible solutions. Limited focus group, interview, or interviews conducted (empathy techniques). The notebook contains some important details of how and why the constraints and criteria were identified.	The notebook contains extensive evidence of U.S. patent searches of existing solutions and multiple sources of verifiable facts of the design problem and multiple industry standards presented for possible solutions. Multiple sources of focus groups, interview, and/or interviews conducted with stakeholders (empathy techniques). The notebook contains all important details of how and why the constraints and criteria were identified.	
Constraints and Criteria: The student will identify all constraints and design criteria for the designed solution.	Accuracy (frequency)	The notebook contains a few constraints and criteria for the designed solution but limited or no rationale for the constraints and criteria.	The notebook contains some constraints and criteria necessary for the designed solution and provides some rationale for the constraints and criteria.	The notebook contains all necessary constraints and criteria for designed solutions and provides clear rationale for the constraints and criteria later to be used to assess the final design decision.	
Generate possible solutions: The student will develop multiple solutions to the identified design problem.	Amount (breadth)	The notebook contains a few possible solutions generated; considering size of design team and time allotted, solutions are not all feasible for the course or skill level of design team.	The notebook contains some possible solutions presented with consideration of size of design team, feasibility for the course, and design team skill level.	The notebook contains multiple possible solutions that are appropriate for the skill level; time allotted; and use of available resource. Proper analyses of the solution are considered in the final design selection.	
Analysis (including optimization) The student provides a rationale for selecting a solution evaluated against identified constraints and criteria and using data to make design decisions such as numerical or computer	Accuracy (frequency)	The notebook contains a rationale for final design solution evaluated against some but not all identified constraints and criteria. Limited use of data to make informed decisions about the selection of a design solution.	The notebook contains rationale for final design solution evaluated against most identified constraints and criteria. Some use of data to make informed decisions about the selection of a design solution.	The notebook contains rationale for final design solution evaluated against all identified constraints and criteria. Solution is selected by using multiple data-driven decisions such as; (examples provided by instructor).	

generated simulations.					
Performance Criteria	**Attribute**	**Performance Level**			**Score**
Design Process Stage		**Low= 1 (6 or below pts)**	**Medium = 2 (7 or 8 pts.)**	**Design Process Stage**	
Prototype: The students create a working model that demonstrates the functionality of the designed solution.	Intensity (clarity and relevancy)	The notebook contains evidence that tine prototype meets some specifications. Prototype has limited functionality; random or inappropriate use of building materials; limited or no manufacturing standards.	The notebook contains evidence that the prototype meets most specifications with moderate functionality. Most materials and construction are appropriate for prototype. Some manufacturing and safety building standards are addressed.	The notebook contains evidence that the prototype meets all specifications identified with complete functionality. All materials used and construction techniques are appropriate for a quality prototype and all manufacturing and safety standards are addressed.	
Testing: The student will conduct appropriate testing of the prototype to assess the quality, safety, and functionality of the design solution.	Accuracy (frequency)	The notebook contains evidence that no testing was done, or prototype tests yielded limited or no evidence of the performance of the design solution based upon identified constraints and criteria. Manufacturing and safety standards were not considered in prototype testing.	The notebook contains evidence that prototype tests were conducted, yielding evidence of the performance of the design solution based upon some identified constraints and criteria and included evidence of meeting some manufacturing and safety standards.	The notebook contains evidence that prototype tests were conducted, yielding strong evidence of the performance of the design solution based upon all identified constraints and criteria and included evidence of meeting all manufacturing and safety standards. Appropriate tests yielded numerical data, field notes, and stakeholder interviews.	
Specification: The students will provide detailed specifications of the final design by providing de- sign drawings, parts lists, and documentation of construction process.	Intensity (clarity and relevancy)	2D or isometric drawing of solution, incomplete parts list and materials list. The process flow chart documenting the construction is incomplete. Limited documentation of equipment used.	Parametric modeling drawing of solution and 2D drawings of prototype. Complete parts list and materials list, but limited details. A complete process flow chart documenting step-by-step construction. Documentation of equipment used.	Parametric modeling drawing of solution and 2D drawings of prototype. Complete parts list and materials list, including data safety sheets, product life-cycle details, manufacturing codes. A complete process flow chart documenting step-by-step construction with photos of the manufacturing process in action. Documentation of equipment used and details of custom jigs if required.	
Notebook Rules: The student will provide an engineer's notebook that follows standard rules and procedures of engineering design record keeping.	Accuracy (frequency)	The student's notebook contains more than three engineer's notebook rule violations. The notebook is missing essential notebook entries, and the notebook is poorly organized.	The student's notebook contains up to three engineer's notebook rule violations. Entries are neat and legible and contain all the essential notebook entries.	The student's notebook is organized and formatted properly according to the engineer's notebook rules. No rules are violated. Entries are neat and legible and contain all the essential notebook entries.	
				Total Score	

ENGINEERING DESIGN RUBRIC

Objective	Performance Level			Score
	Needs Improvement = 1	**Good = 2**	**Excellent = 3**	
Design Product	Product marginally meets design problem requirements (unclear function, too expensive or impractical to product, not safe, does not meet constraints)	Good (average) product meets basic design problem requirements (functions okay, produced within cost limits, meets constraints, meets some criteria, safety okay)	High quality (above average) product that meets and exceeds design problem requirements (meets budget, constraints, criteria, clearly safe and functions well)	
	Product displays poor (below average) workmanship	Product displays good (average) workmanship	Product is aesthetically appealing and displays high quality (above average) workmanship	
	Product lacks evidence of originality and creativity; marginally addresses design problem	Product shows some evidence of creativity and inventiveness; addresses design problem	Product shows significant evidence of originality, creativity and inventiveness; effectively addresses design problem	
Design Process	Little evidence that external research was conducted to identify and describe nature of design problem to be solved	Evidence that some research was conducted to identify and describe nature of problem to be solved	Supporting evidence (research notes, illustrations, etc.) of external research identifying and describe nature of problem to be solved; research clearly documented in design notebook	
	Little evidence that students formulated design criteria and constraints prior to selecting alternative solutions	Evidence that students formulated design criteria and constraints prior to selecting alternative solutions	Evidence that students formulated design criteria and constraints prior to selecting alternative solutions; clearly documented how criteria and constraints were developed in design notebook	
	Little evidence that idea generation strategies (e.g. brainstorming, teamwork, etc.) were used to generate alternative solutions to solve design problem	Evidence that idea generation strategies (e.g. brainstorming, teamwork, etc.) were used to generate alternative solutions to solve design problem	Evidence that idea generation strategies (e.g. brainstorming, teamwork, etc.) are clearly documented in design notebook and were used to generate alternative solutions to solve design problem	
	Little evidence that mathematical models were used to optimize possible solutions, incorporating identified constraints, criteria, and stakeholder needs	Evidence that mathematical models were used to optimize and describe possible solutions, incorporating constraints, criteria, and stakeholder needs	Evidence that mathematical models were clearly documented in design notebook and used to optimize, describe, and predict outcomes for possible solutions, incorporating identified constraints, criteria, and stakeholder needs	
	No evidence that a prototype model of the best conceived solution was constructed and analyzed	Evidence that a prototype model of best conceived solution was constructed and some analysis conducted	Evidence that a prototype model of best conceived solution was constructed and analyzed, procedures/materials used were	

			clearly documented in design notebook	
Objective	**Performance Level**			**Score**
	Needs Improvement = 1	**Good = 2**	**Excellent = 3**	
Design Process	No evidence that test procedures were conducted to illustrate workability of model or prototype, neither were they documented in design notebook	Evidence that some test procedures were conducted to illustrate that model or prototype functioned and met specified constraints and criteria	Supporting evidence that test procedures were conducted to illustrate that model or prototype worked and met specified constraints and criteria; limitations were clearly documented in design notebook	
	No evidence of iteration taking place in the design process	Some evidence that iteration took place throughout the design process	Supporting evidence that iteration took place throughout design process and details are clearly documented in design notebook	
Communication	Reports and presentations lacked clarity	Reports and presentations describing design processes were provided and legible	Reports and presentations describing design processes were detailed clearly and provided in design notebook	
	Design notebook entries were incomplete and lacked some key information	Clear and concise design notebook entries that are complete and without error	Clear and concise design notebook entries that illustrate complete, precise sketches, calculations and notes that correlate with product	
Teamwork	Individuals were frequently absent and team did not work as a unit	Team worked as a unit and was well organized	Team worked as a functional inter-disciplinary unit and was well organized; complete assigned tasks on time or early	
	No evidence of team planning; team did not finish project within specified time	There was some evidence that team planned effectively and worked within time constraints to complete project	Team planned effectively, allocated group resources, documented activities in design notebook, and completed project within time constraints	
			Total Score	

Design Activity	Duration (S, M, L)	Frequency
Understanding the Problem		
Identify the need		
Define the problem		

OBSERVATIONS/ NOTES:

Date	Observations

Design Activity	Duration (S, M, L)	Frequency
Defining the Problem Space		
Search for solutions		
Identify constraints / criteria		

OBSERVATIONS/ NOTES:

Date	Observations

Design Activity	Duration (S, M, L)	Frequency
Generating Solutions		
Generate alternative solutions		

OBSERVATIONS/ NOTES:

Date	Observations

Design Activity	Duration (S, M, L)	Frequency
Solution Analysis		
Analysis / Predictions		
Optimization		
Decision		

OBSERVATIONS/ NOTES:

Date	Observations

Design Activity	Duration (S, M, L)	Frequency
Build and Communicate		
Prototype		
Design Specifications		
Communicate Results		

OBSERVATIONS/ NOTES:

Date	Observations