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Academic Performance as a Predictor of Student Growth in Achievement and Mental Motivation During an Engineering Design Challenge in Engineering and Technology Education

Nathan Mentzer
Utah State University

ACADEMIC PERFORMANCE AS A PREDICTOR OF STUDENT GROWTH IN ACHIEVEMENT AND MENTAL MOTIVATION DURING AN ENGINEERING DESIGN CHALLENGE IN ENGINEERING AND TECHNOLOGY EDUCATION

by

Nathan James Mentzer

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Approved:

Dr. Kurt Becker Major Professor	Dr. Jamison Fargo Committee Member
Dr. Christine E. Hailey Committee Member	Dr. Martha T. Dever Committee Member
Dr. Ning Fang Committee Member	Dr. Byron R. Burnham Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

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ABSTRACT

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Nathan James Mentzer, Doctor of Philosophy

Utah State University, 2008

Major Professor: Dr. Kurt Becker
Department: Engineering and Technology Education

The purpose of this correlational research study was to determine if students' academic success was correlated with: (a) the student change in achievement during an engineering design challenge; and (b) student change in mental motivation toward solving problems and critical thinking during an engineering design challenge. Multiple experimental studies have shown engineering design challenges increase student achievement and attitude toward learning, but conflicting evidence surrounded the impact on higher and lower academically achieving students.

A high school classroom was chosen in which elements of engineering design were purposefully taught. Eleventh-grade student participants represented a diverse set of academic backgrounds (measured by grade point average [GPA]). Participants were measured in terms of achievement and mental motivation at three time points.

Longitudinal multilevel modeling techniques were employed to identify significant predictors in achievement growth and mental motivation growth during the school year. Student achievement was significantly correlated with science GPA, but not math or communication GPA. Changes in achievement score over time are not significantly correlated with science, math, or communication. Mental motivation was measured by five subscales. Mental focus was correlated with math and science GPA. Mental focus increases over time were negatively correlated with science GPA, which indicated that the initial score differential (between higher and lower science GPA students) was decreased over time. Learning orientation and cognitive integrity were not correlated with GPA. Creative problem solving was correlated with science GPA, but gains over time were not correlated with GPA. Scholarly rigor was correlated with science GPA, but change over time was not correlated with GPA.

(284 pages)

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Lifelong learning is a challenge. As a society, we value knowledge and recognize intellectual development as a key to sustainability. This dissertation represents the quest for knowledge made possible by the support of an academic community of dedicated educators.

While in my handwriting, this research could not have been completed without the loving support of Fay, who provided emotional stability, strength, and her ubiquitous confidence in my capacity to grow. Everest, at age 2, displayed his support of learning by loading his tricycle trunk with books and proudly announcing, “I am going to school to do research, bye, bye, I love you,” as he zoomed across the living room.

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teachers as they apply engineering design processes to technological problems.

Nathan James Mentzer

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CHAPTER I

INTRODUCTION

Technological literacy is an important educational goal for all high school students (International Technology Education Association [ITEA], 2000). Scholars in technology education and engineering disciplines, as well as the general public, are expressing the need for technological literacy and asserting that our K-12 educational system must address the issue (Gamire & Pearson, 2006; Gorham, 2002; ITEA, 1996, 2000; Pearson & Young, 2002). The impacts of our decisions related to technologies are complex, and the ability to make thoughtful decisions regarding the relationship between society and technology is essential for our nation's continued economic prosperity (Pearson & Young).

Though a need for a technologically literate citizenry is evident, many people do not possess the literacy to make informed decisions about technology. The ability for consumers, as well as business and political leaders, to weigh the impacts and implications of their decisions regarding the use and development of technologies is essential but currently insufficient (Pearson & Young, 2002).

In *Standards for Technological Literacy* (STL), published by the ITEA, engineering in general, and engineering design, specifically, is included. Including engineering content in technology education curricula demands the field identify successful approaches to teaching engineering at the high school level. Engineering design challenges include the application of engineering principles to solve real world problems with an active, hands-on approach. Incorporating engineering design challenges in formal coursework is one method of teaching the engineering process through practical application. “In brief, available research suggests that these kinds of courses appear to improve retention, student satisfaction, diversity, and student learning” (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 114).

Researchers have considered the impact of gender, ethnicity, socioeconomic status, and age of student participants as factors related to student experience during the engineering design challenge. However, limited and conflicting evidence suggests the academic background of a student may impact their experience during the engineering design challenge. Technology education students typically represent a broad range of academic backgrounds, and, therefore, it is essential that we understand how engineering design challenges effects all students from low achieving to high. As technology education classes consider infusing engineering design, a natural concern emerges; does a student’s general academic success correlate with student achievement and mental motivation during an engineering design challenge?

The practical significance of this question is based on the nature of technology education student clientele. Technology education students represent a continuum of students ranging from academically successful to struggling in school. A variety of experimental studies have shown engineering design challenges increase student achievement and attitude toward learning (Cantrell, Pekca, & Ahmad, 2006; Dally & Zhang, 1993; Dunlap, 2005; Dym et al., 2005; Griffith, 2005; Irwin, 2005; Lentz & Boe, 2004; Marra, Palmer, & Litzinger, 2000; Ricks, 2006; Romero, Slater, & DeCristofano, 2006; Roselli & Brophy, 2006; Weir, 2004; Yaeger, 2002). If growth in student achievement and motivation is uniform and uncorrelated with a general indicator of student success in school, infusing engineering concepts into technology education will be successful for all students. The primary motivation behind this study is the concern that student growth may not be uniform, and a correlation may exist with a student's academic nature. If only highly successful students grow, or show dramatically higher growth than their less academically successful counterparts, caution must be used when implementing this educational strategy in a mixed class.

Purpose and Objectives

The purpose of this correlational research study was to determine if a student's academic success, measured by grade point average (GPA), is correlated with: (a) student change in achievement during an engineering design challenge; (b) student change in mental motivation toward solving problems and critical thinking during an engineering design challenge.

The following objectives will address the purpose of this study.

1. Use longitudinal multilevel modeling techniques to correlate data on student grade point average scores with pre-, mid-, and post-achievement testing.

2. Use longitudinal multilevel modeling techniques to correlate data on student grade point average scores with pre, mid, and post mental motivation testing.

Procedures

The objectives of this study employ longitudinal multilevel analysis to establish correlation. As stated by Gall, Gall, and Borg (1999),

> Correlational statistics are used for two primary purposes in educational research: (1) to explore the nature of the relationship between variables of interest to educators, and (2) to determine variables that can be used to predict important educational or personal characteristics of individuals that will not occur until later. (p. 219)

The sample for this study included technology education students in two sections of "Industry & Engineering Systems" (Appendix A). This course; offered by an urban northwestern high school, was team taught by two teachers. The total enrollment for the two sections was 53 on the first day of class and dropped to 41 by the conclusion of the year. Both sections were taught by the same instructors with the same content and methods. This course was a year long and combined the concepts of engineering and technology education through two corequisite classes. Students received a science credit for the engineering as an applied physics class and an industrial technology credit for the materials processing and fabrication class.

The instructors of this course delivered a hands-on experience which aligned in content and delivery with typical technology education philosophy. The focal point of this course was an engineering design challenge in the spring term. In preparation for the challenge, students experienced a fall semester comprised of lecture and hands-on application of engineering (as applied physics) and metal fabrication technologies. Typical concepts included: motion, magnetism, electric motors, energy, power, forces, electricity, heat, and air pressure, as well as welding, machining, mechanical fasteners, cutting, and bending metals.

The infusion of engineering concepts into technology education courses was a key element of this study. This was accomplished by applying the engineering concepts as related to physics, science, and math to a traditional technology education curriculum, and culminating with an engineering design challenge. The delivery of engineering concepts and technology education concepts was a central phenomenon to this research site. In this classroom, a technology education teacher had partnered with a physics teacher to deliver engineering content in a technology education atmosphere. While team teaching may provide many benefits, it is a rare occurrence. In generalizing the findings of this study, it is assumed that one teacher, skilled in technology education and familiar with engineering design methodologies, may be equally competent in delivering an engineering design challenge to a group of technology education students.

Data were gathered from student high school transcripts. This indicator of general academic aptitude will be considered as four factors: cumulative GPA, math GPA, science GPA, and reading/literature GPA. Additional data included a series of two tests. These tests assessed achievement and mental motivation. The two tests were administered on three occasions during the school year. Longitudinal multilevel analysis techniques were utilized to identify correlations between a student’s academic history and change in achievement during the engineering design challenge course. Mental motivation to apply critical thinking to solve challenging problems was also correlated to a student’s academic history with longitudinal multilevel analysis.

This correlational study did not inquire about the efficacy of an engineering design challenge. Previous quasi-experimental research (Cantrell et al., 2006; Dally & Zhang, 1993; Dunlap, 2005; Dym et al., 2005; Griffith, 2005; Irwin, 2005; Lentz & Boe, 2004; Marra et al., 2000; Ricks, 2006; Romero et al., 2006; Roselli & Brophy, 2006; Weir, 2004; Yaeger, 2002) has established that engineering design challenges are successful in increasing student achievement and attitude toward learning. To build upon this research base, this study addressed the potential relationship between students' academic history, measured by GPA, and their experience during an engineering design challenge as measured by a cognitive achievement test and mental motivation test.

Research Questions

The broad research question for this study was: *Do high school students of various academic backgrounds experience success equally as a result of an engineering design challenge?* More specifically, this study had two main research questions. These questions were analyzed and evaluated for practical and statistical significance in the field.

1. Does a general indicator of previous academic success serve as a significant predictor of student learning as measured by an achievement test?
2. Does student motivation toward solving problems and applying critical reasoning skills correlate with a general indicator previous academic success?

Definition of Terms

Engineering design challenge: For purposes of this research, an engineering design challenge was defined as a team based activity in which students engage in solving a real world problem. In this engineering design challenge, mathematical models were developed to predict the behaviors of systems involved. Generally, physics and material properties provided insight as to what variables are important considerations for the desired outcomes. The data extracted from manipulating models served to guide experimentation. Design decisions were made based on model and experimental results.

Integrative review: Integrating modern bodies of literature demand more sophisticated techniques of measurement and statistical analysis. Glass (1977) summarized an integrative review:

> The accumulated findings of dozens or even hundreds of studies should be regarded as complex data points, no more comprehensible without the full use of statistical analysis than hundreds of data points in a single study could be so casually understood. Contemporary research reviewing ought to be undertaken in a style more technical and statistical than narrative and rhetorical. (p. 352)

Effect size: "The term effect size suggests that the difference in two populations is the effect of something…" (Cohen, 2001, p. 218). This measurement was in terms of standard deviations and was calculated by subtracting the mean of the control group from the mean of the treatment group and dividing the difference by the standard deviation of the control group.

Longitudinal research: "In longitudinal research, researchers collect data from either the same or a different sample from a given population at two or more separate points in time" (Gall et al., 1999, p. 175).

Multilevel analysis: "The term 'multilevel' refers to a hierarchical or nested data structure, usually people within organizational groups, but the nesting may also consist of repeated measures within people, or respondents within clusters as in clusters sampling" (Hox, 2002, p. ix). "Longitudinal data, or repeated measures data, can be viewed as multilevel data, with repeated measurements nested within individuals" (p. 73).

Parsimonious: Longitudinal multilevel modeling techniques purge the non-significant effects from the model in order to identify a simpler model that is not over-fitted or too sample specific. The simpler model does not statistically differ in its prediction capacity and is known as parsimonious (Tabachnick & Fidell, 2007).

California Measure of Mental Motivation (CM3): As published by Insight Assessment (2007a):

> Critical thinking (CT) is now widely recognized as an essential educational outcome and a powerful and vital resource in one's personal and civic life. Educators and employers now seriously acknowledge the centrality of critical thinking throughout the levels of K-12 and post secondary education. (p. 3)

"The term critical thinking *disposition* refers to a person's internal motivation to think critically when faced with problems to solve, ideas to evaluate, or decisions to make" (Insight Assessment, 2007a, p. 3). "The CM3 is designed to measure the degree to which an individual is cognitively engaged and mentally motivated toward intellectual activities that involve reasoning" (Insight Assessment, p. 4).

Professional development: Glickman, Gordon and Ross-Gordon (2004) suggested:

> The essence of successful instruction and good schools comes from the thoughts and actions of the professionals in the schools. So, if one is to look for a place to improve the quality of education in a school, a sensible place to look is the continuous education of educators—that is, professional development. (p. 370)

For the purposes of this study, a skill development program format was implemented, "This consists of several workshops over a period of months, and classroom coaching between workshops to assist teachers to transfer new skills to their daily teaching"

(Glickman et al., 2004, p. 375).

Limitations of the Study

This study was conducted in an urban northwestern city with a population of 200,000 according to the city's website. Porter Valley High School (pseudonym) served 1,500 student in grades 9-12. Students enrolled in the elective course "Industry & Engineering Systems" were juniors pursuing a science and industrial technology credit. Ethnic diversity in this course was typical of northwestern communities with white students comprising the majority population. Students from underrepresented populations in engineering and technology comprised approximately 20% of the students enrolled in this elective course.

Assumptions of the Study

The following assumptions were made regarding this study.

1. Students in the course participated voluntarily in the study.
2. Students participating in the pilot study were similar to the students in the study.
3. The instruments utilized for gathering data accurately measured achievement and mental motivation.
4. Both course sections were taught equally.
5. Researcher's presence did not affect results of this study.

CHAPTER II

REVIEW OF LITERATURE

Problem Statement

Technological literacy is an important educational goal for all high school students. Experts in technological fields, and the general public, are expressing the need for technological literacy and asserting that our K-12 educational system must address the issue (Gamire & Pearson, 2006; Gorham, 2002; ITEA, 1996, 2000; Pearson & Young, 2002). The impact of decisions related to technologies are complex, and the ability to make thoughtful decisions regarding our relationship between society and technology is essential for our nation's continued prosperity.

Though a need for a technologically literate citizenry is evident, many people do not possess the literacy to make informed decisions about technology. The ability for consumers, as well as business and political leaders, to weigh the impacts and implications of their decisions regarding the use and development of technologies is essential but currently insufficient.

Most experts agree that technological literacy includes an understanding of engineering design. In the STL published by ITEA, engineering in general, and engineering design, specifically, is included. To include engineering content in technology education curricula demands the field identifies successful approaches to teaching engineering at the high school level. Engineering design challenges are one method of teaching the engineering process through practical application.

Research shows that engineering design challenges have successfully improved student achievement and attitude toward learning (Cantrell et al., 2006; Dally & Zhang, 1993; Dunlap, 2005; Griffith, 2005; Irwin, 2005; Lentz & Boe, 2004; Marra et al., 2000; Ricks, 2006; Romero et al., 2006; Roselli & Brophy, 2006; Weir, 2004; Yaeger, 2002). Engineering design challenges have been implemented and researched in elementary school through college and include the application of engineering principles to solve real world problems with an active, hands-on approach.

Researchers have considered the impact of gender, ethnicity, socioeconomic status and age of student participants as factors related to student experience during the engineering design challenge. However, available evidence suggests the academic background of students may impact their experience during the engineering design challenge (Cantrell et al., 2006; Weir, 2004). Technology education students, typically, represent a range of academic diversity, while engineering students tend to be high achievers in math and science courses. As technology education classes consider infusing engineering design, a natural question emerges: does a student’s general academic success influence their achievement and mental motivation during an engineering design challenge?

Technological Literacy

Study Selection Criterion

The need for technological literacy has been well documented in the last ten years. Journals such as the *Technology Teacher*, *The Journal of Engineering Education*, *Journal of Technology Education*, and the *Journal of Industrial Technology Teacher Education* are rich in evidence that a need exists. The National Academy of Engineering has been actively participating in the development of a body of literature identifying, assessing, and supporting the relationship between technological literacy and engineering education. The body of literature addressing technological literacy in this integrative review was selected based on the following criteria: (a) publication date of 1997 or later; (b) publication must be peer reviewed; and (c) publication must address technological literacy. Literature meeting the above criteria was coded for evidence of (a) the need for technological literacy, (b) a lack of technological literacy in U.S. society, (c) value of engineering as related to technological literacy, and (d) value of the STL.

Combinations of the following keywords were used to develop this body of literature: engineering, high school, middle school, junior high, elementary, technological literacy, standards for technological literacy, engineering education standards, design challenge, problem based learning, challenge based instruction, cornerstone, capstone. In addition to the journals mentioned above, the following databases were searched: ERIC via EBSCO Host, Digital Dissertations, Wilson and Google Scholar. The summary of this data may be found in Appendix B.

Defining Technological Literacy

Three influential works have been recognized by the field of technology education as having orchestrated a foundation for defining technological literacy: *STL*, *Technically Speaking* and *Tech Tally*. A unifying theme emerging from these publications was that technologically literate people are able to function in our modern technological society (Gamire & Pearson, 2006; ITEA, 2000; Pearson & Young, 2002). More specifically, technologically literate people must be knowledgeable, capable, critical thinkers, and decisions makers. *The STL*, published by ITEA, established a formal definition of technological literacy, “Technological literacy is the ability to use, manage, assess, and understand technology” (ITEA, p. 9). The uniform message is strong—people need to be technologically literate in order to be active, functioning members of our modern society.

A Need for Technological Literacy

Sixty-six articles were identified relating to the need for technological literacy. Two articles specifically focused on the ITEA Gallup Polls (2002/2004) as measurements demonstrating the general public’s perception of a need for technological literacy. Sixty-four articles directly supported the need for a technologically literate society, each pointing toward K-12 and/or post secondary education as the delivery mechanism for reaching this goal.

The typical article supports the *STL* as a guide for promoting the development of technologically literate students. Generally, articles relied on the increasingly complex nature of our technologically advanced society as evidence that students must be capable of thinking critically about issues regarding technology in order to be highly functional contributors in society. Weber explained, “With the increasing complexity of technology, it is important for each citizen to be able to make informed decisions about the technology that he or she uses" (2005, p. 28).

Dugger, Meade, Delany and Nichols (2003), who were an instrumental force in developing the *STL*, reiterates their importance as related to developing a healthy, prosperous economic foundation for the U.S. economy. Meade adds agreement regarding the ubiquitous nature of technology, "technology is everywhere, and that all students need technological literacy" (2004a, p. 18).

Gallup Polls were commissioned to identify a national perspective on technological literacy. A 2004 poll provided the opportunity to deepen and verify some of the conclusions drawn in 2002:

> Three conclusions drawn in the earlier study are both reinforced and extended by the additional data reported herein. They are repeated and slightly revised in the following: (a) The public understands the importance of technology in our everyday lives and understands and supports the need for maximizing technological literacy. (b) the public wants and expects the development of technological literacy to be a priority for K-12 schools. (c) men and women are in general agreement on the importance of being able to understand and use technology and on the need to include technological literacy as part of the schools' curriculum. (Rose, Gallup, Dugger, & Starkweather, 2004, p. 11)

These typical examples are representative of the 64 articles supporting the need for technological literacy. This expression of need is triangulated between experts in the field and a national sample of the general public.

A Lack of Technologically Literate People in the U.S.

Of the 66 articles related to technological literacy, 28 directly addressed the current status of technological literacy in the United States. All 28 articles detailed perspectives that highlighted the lack of an adequate level of technological literacy.

Concerns hinge on the concept that technological literacy is a tool of understanding which can provide personal and professional opportunities, and a lack of literacy leads to ill-informed decision making. Russell (2005) explained:

> For example, citizens often find themselves in a position of needing to vote about certain issues that are very technological. They may not be well informed regarding these issues, yet need to make a decision on how to vote. (p. 23)

Typically, publications refer to the lack of technologically literate employees in the U.S. labor market, “In addition, technical positions are currently unfilled due to the lack of a workforce with a sustained, if not growing, level of technological competency and a populace with a higher level of technological literacy” (Gorham, Newberry, & Bickart, 2003, p. 95). The demand for and lack of technologically literate people for the purposes of a strong society, capable political leaders, and cutting-edge economic advantages is voiced clearly in these publications.

Technological Literacy Includes an Understanding of Engineering

The role of engineering in developing technological literacy has been established in the *STL*. ITEA has identified 20 standards for facilitating the development of technological literacy. Standard number nine reads, “Students will develop an understanding of engineering design” (ITEA, 2000, p. 210). Support for the inclusion of engineering design in the field of technology education was evident in 65 of the 66 articles that clearly articulated direct support for the *STL*. Thirty-three of these articles, specifically, mention engineering. This reference to engineering is further evidence of its particular importance to experts in the field. The articles that refer to engineering did not state all 20 standards. Rather, these articles identified key standards for discussion. Gorham and colleagues (2003) described a synergistic relationship between engineering and technology education toward a common goal of technological literacy, suggesting the Engineering Criteria 2000 and *STL* (compared in Appendix C) show “clear connections” (p. 97).

As suggested by Hailey, Erekson, Becker, and Thomas (2005), “The design process described in [STL] Standard 8 is very similar to the introductory engineering design process described in freshman engineering design texts with two notable exceptions” (p. 24).

> The first highlighted difference shows the role of analysis in introductory engineering design compared with Standard 8, which prescribes selecting an approach, making a model or prototype, and testing the approach. Engineering programs teach analysis as the decision making tool for evaluating a set of design alternatives, where ‘analysis’ means the analytical solution of a problem using mathematics and principles of science. (pp. 24-25)

> The second highlighted difference shows the importance of creating or making the designs, as prescribed by Standard 8, in contrast with the introductory engineering design process, which prescribes that students develop ‘design specifications’ so someone can create the design, not necessarily the engineer or engineering student. (p. 25)

Appendix D shows a graphic comparison the two design processes published by Hailey and colleagues.

Gattie and Wicklein (2005) compared the design process of engineering with that of technology education and conclude that similarities exist but differentiation is primarily involved with the application of math and science for predictive analysis:

> The technology education design process is directed toward the construction of a prototype model that can be tested for failure or success, but lacks the mathematical rigor that would enable the process to be repeated. Moreover, the

> absence of analysis precludes the development of predictive results. This fundamental difference is the basis for change within the current technology education paradigm suggested in this paper, and is reflected by the survey results. (p. 8)

This review suggests that one key component of engineering which may be infused into the technology education design process is the mathematical and scientifically based analytical steps necessary for prediction prior to prototyping. *Technically Speaking* serves as further evidence of the need for an understanding of engineering as part of developing technological literacy. "An engineering-led effort to increase technological literacy could have significant, long-term pay-offs, not only for decision makers in government but also for the public at large" (Pearson & Young, 2002, p. 112).

Lewis (2005) suggested that one method of integrating engineering and technology education is through design challenges. This further corroborates the position made by Gorham and colleagues (2003) that a synergistic relationship is evident between the fields. Often, technology educators pose design challenges to students. As students progress through the technology education design model, the addition of predictive analysis to this procedure would facilitate the integration of engineering design. Lewis commented:

> Design appropriate for technology education is characterized by open-ended problems where the designer bridges the gap between past experiences and the current problem to be solved; one method of achieving this transition is through engineering design challenges. (p. 49)

Characteristics of Engineering Design

The definition of engineering design has been established by the Accreditation

Board for Engineering and Technology (ABET, 2007):

> Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs. (p. 21)

Karl Smith (2000), in a reflective column in the *Journal of Engineering Education*, surveyed the teaching of engineering design focusing on the first and second year students. Smith highlights several texts which articulate engineering design on a level appropriate for early design experiences. *Introduction to Engineering Design*, by Eide, Jenison, Mashaw, and Northup (2001) was among the noteworthy texts and corroborates a similar proposition regarding an engineering design model by Dym and colleagues (2005). Table 1 draws a comparison between the Eide and Dym models of design. The Eide model is presented as a series of steps in an iterative process, however, for purposes of clarity, is shown through association with the underlying principles of the Dym model.

Table 1

Comparison of Eide and Dym Models for Engineering Design

Dym Model (2005)	Eide Model (1998, 2001)
Design thinking as divergent-convergent questioning	Identify the need /define problem/identify constraints/ specify evaluation criteria
Thinking about designing systems	
a. Thinking about systems dynamics	Define problem/identify constraints
b. Reasoning about uncertainty	Analysis/mathematical predictions
c. Making estimates	Analysis/mathematical predictions
d. Conducting experiments	
Making design decisions	Search for solutions/generate alternative solutions/ optimization/decision/design specification
Design thinking in a team environment	
The language of engineering design	Analysis/mathematical predictions/communicate design specification

Key elements of engineering design for this study are outlined in Table 2. These elements represent a synthesis of the two models outlined in Table 1.

Problem Definition

Problem definition includes addressing well-defined and ill-defined questions, as stated by Dym and colleagues (2005):

> No sooner has a client or professor defined a series of objectives for a designed artifact than the designers–whether in a real design studio or in a classroom–want to know what the client really wants. What is a safe product? What do you mean cheap? How do you define the best? (p. 104)

As part of defining the problem, a clear view of the need must be articulated in association with identifying the constraints governing the problem. This clear view of the

Table 2

Synthesis of Key Elements of Engineering Design

Element	Characteristics
Problem definition	Questioning Constraints Component/system level Evaluation criteria
Solutions	Research existing Brainstorm alternative
Analysis/modeling	Prediction Uncertainty Estimation
Experimentation	Empirical data gathering Based on analysis Prototyping
Decision making	Evaluation of potential solutions Optimizing
Teamwork	Working effectively on teams Communications

problem and its boundaries is well articulated in the literature and these two design models.

Solutions

Multiple solutions are identified through two venues: research existing solutions and creatively brainstorming alternative solutions. Strong design teams gather information from multiple sources, judge its quality, document their efforts (Davis, Gentili, Trevisan, & Calkins, 2002).

Analysis/Modeling

"Mathematical or analytical models used to express some aspect of an artifact's function or behavior, where the behavior is in turn often derived from some physical principle(s)" (Dym et al., 2005, p. 108). This analysis should consider technical, financial, system, life-cycle, and potential failure (Davis et al., 2002). Modeling approaches are limited and incomplete at times, and, therefore, statistical tools should be considered to further understanding of the phenomenon. Estimation may be used since systems are complex, and modeling every aspect of the behavior is not always practical (Dym et al., p. 106).

Experimentation

Experimentation is guided by analysis and modeling for purposes of validating the model and providing empirical evidence where data is insufficient. "The design of systems is rarely accomplished exclusively by applying fundamental scientific principles. In most cases, the design of systems also requires some use of empirical data and experimentation” (Dym et al., 2005, p. 106). An interactive relationship between experimentation and modeling serves to guide the development of understanding and design progression (Box & Liu, 1999).

Decision Making

“[D]esign is a rational process of choosing among alternatives” (Dym et al., 2005, p. 107). A decision matrix helps assist students in objectively considering the alternatives based on their advantages and disadvantages (Gomez, Oaks, & Leone, 2004). Quality design decisions involve full team participation and consensus and an optimized solution based on iteration and refinement (Davis et al., 2002).

Teamwork/Communications

ABET criterion 3(d) articulates a need for students to function on a multidisciplinary team. “[B]oth cornerstone and capstone project based courses are seen as opportunities to improve students’ ability to work in teams, as well as their communication skills” (Dym et al., 2005, p. 107). Good teams exhibit characteristics such as clear purpose, defined roles and responsibilities, inspiring climate and attitude, effective resource management, and an incentive implementation plan (Davis et al., 2002). An essential component of design team success is communications. “Different languages are employed to represent engineering and design knowledge at different times, and the same knowledge is often cast into different forms or languages to serve different purposes" (Dym et al., p. 108). Dym further suggested multiple communication mediums which include verbal, graphical, mathematical or analytical models, and numerical.

Engineering Design Challenge

Literature describing the engineering design challenge draws on various terms, which, while not synonymous, do refer to similar pedagogical approaches of interest to this study. The terms project based learning (PBL; Dym et al., 2005), active learning (Yaeger, 2002), problem based learning (Dunlap, 2005; Griffith, 2005; Irwin, 2005), challenge based instruction (CBI; Roselli & Brophy, 2006), interactive learning activities (Cantrell et al., 2006), project-driven approach (Dally & Zhang, 1993), design challenge (Romero et al., 2006), cornerstone design (Dym et al.), capstone design (Dym et al.), and team-based project-learning (Marra et al., 2000), all serve to generate literature for this review which embodies the following working definition of engineering design challenge.

For purposes of this research, an engineering design challenge was defined: The engineering design challenge is a team based activity in which students engage in a real world problem. This iterative approach is initiated by negotiation of the problem definition. Design teams and clients work together to establish their problem and constraints. Information provided by modeling and analysis may illuminate new concerns or possibilities which encourages revisiting the problem definition.

Models are developed to predict the behaviors of systems involved. Generally, physics and material properties provide insight as to what variables are important considerations for the desired outcomes. These models may be simplistic and serve as estimates or complex and very closely represent actual system behavior. The data extracted from manipulating models serves to guide experimentation. The results inform model refinements. This cyclical nature is the key component differentiating engineering design challenges from other problem solving methodologies. Decisions are made based on model and experimental results. These decisions lead to optimizing the system based on the problem as defined by the client and engineering design team.

The design challenge should integrate principles, concepts, and techniques learned in earlier engineering courses (Napper & Hale, 1999). The techniques learned previously can be contextualized and applied in the challenge. As stated by Marin, Armstrong, and Kays (1999):

> Students must first learn to crawl before they can walk or run. This means there must be sufficient course work in the appropriate engineering science upon which the capstone design experience will be built. The engineering science content of this course work should focus on the creative application of mathematical and scientific knowledge that is appropriate for the modern engineering practice of the engineering discipline. (p. 19)

The application of mathematical and scientific knowledge is most frequently evident in modeling system behaviors. These models are representations in which the physical characteristics of a system can be described mathematically for prediction and explanation.

As students are posed with ill-defined problems and expected to synthesize previously learned material in order to develop a solution to a problem, the need for leadership and mentorship arises (Napper & Hale, 1999). The mentorship must focus on encouraging the student to take ownership of the problem and its design which includes problem definition. Students do not need to “solve” all aspects of a chosen problem. Rather, they should narrow their focus to one or two key elements of the design and do a thorough job on these elements.

Students also need to be team leaders and are expected to take lead roles at different times during the design process. Carrol and Hirtz (2002) corroborate the Marin, Armstrong and Kay proposition that leadership and project management are key components of the design challenge, but also reinforce the need for mathematical modeling and a manufacturing consideration (p. 245). In their article, the challenge included designing a solar race car for the *Sunraycer* competition with two objectives: providing a multidisciplinary approach to the teaching and learning process and integrating new students into a design team. Teamwork is a critical aspect of the learning experience as design challenges (in the case of a solar powered race car) may be so complex that a single student could complete the challenge in a practical timeline.

Engineering Design Challenges

Published Integrative Literature Reviews

No quality integrative reviews have been published which effectively address the issue of engineering design challenge efficacy related to student learning. Clive Dym, a well-recognized authority in the field of engineering education, draws the following conclusion, “In brief, available research suggests that these kinds of courses appear to improve retention, student satisfaction, diversity, and student learning" (Dym et al., 2005, p. 114). His judgment, while corroborated by other experts in the field, is based in data, "Beyond the anecdotal data (e.g., [125]), there is hard evidence that supports these assertions [126-138]. Assessment and outcomes research has been done much more vigorously in recent years (see [126] for a comprehensive survey)" (p. 110). A sample of four publications were reviewed from his 12 references and led to concerns regarding the quality of this "hard data" in addressing his claims on student satisfaction and student learning. Dym's comprehensive survey, reference #126, (Adams, Turns, Martin, Newman, & Atman, 2004), was intended for publication but was not printed. The lead author returned an email copy of this revised paper, later published in 2006 (Turns et al., 2006). This revision, however, is no longer a comprehensive survey addressing the assessment and outcome of engineering design challenge based instruction.

Dym cited Pavelich and Moore (1996), whose study compared engineering freshmen to sophomores and freshmen to seniors and attributed intellectual development to the engineering design experiences. The internal validity of this study is low since the effect of maturation and history may account for the developmental changes rather than the treatment of engineering design experiences. Adams, Turns, and Atman (2003) compared freshmen and senior engineering students at the university level. However, they did not distinguish between students who had experienced engineering design challenges. Therefore, the developmental data gathered, and conclusions drawn, do not support the assertion that engineering design was the primary influential factor. The last study considered in the judgment regarding the quality of literature surveyed by Dym was published by Olds and Miller (2004), which surveyed students 4, 5, and 6 years after their experience with a freshmen design course and attributed student success to this one isolated event. This conclusion elicits concern regarding the internal validity of the study, specifically, maturation and history. In conclusion, while experience may have led Dym to appropriate conclusions which passed the peer review process, this sample of data was determined to be low quality, generally, addressing the assertion of retention rather than student satisfaction or student learning. Of the four references sampled, internal validity issues and external validity issues could account for the findings rather than the engineering design experiences. The remaining eight references included studies on general retention data, rather than student learning and attitude toward learning, and included personal communications which were not published, as well as a reference to a resource online which was no longer available.

Study Selection Criterion

A body of literature was established to shed light on the efficacy of engineering design challenges related to student learning and attitude toward learning. Engineering design challenges have been of increasing interest in the domain of engineering and technology education in recent years. Literature was reviewed from sources including the *Technology Teacher, The Journal of Engineering Education, Journal of Technology Education, Journal of Industrial Technology Teacher Education*, and the *National Academy of Engineering*.

For purposes of this review, 13 studies have been selected. Selection criteria included the following: (a) publication date of 1993 or later; (b) publication must be peer reviewed; and (c) research must focus on engineering content delivered using the characteristics of an engineering design challenge defined for this study. Literature meeting the above criteria was coded for evidence of (a) research design, (b) student achievement, (c) student attitude toward learning, and (d) study quality.

Combinations of the following keywords were used to develop this body of literature: engineering, high school, middle school, junior high, elementary, technological literacy, standards for technological literacy, engineering education standards, design challenge, problem based learning, challenge based instruction, cornerstone, capstone. In addition to the journals mentioned above, the following databases were searched: ERIC via EBSCO Host, Digital Dissertations, Wilson, and Google Scholar.

Studies were discovered, but rejected, which exhibited extremely low internal validity. Validity was considered extremely low if the results could be attributed entirely to other events or variables rather than the independent variables in the study. After the selection criteria had been met, data were gathered from each study and was summarized in Table 3.

Each study was either of quantitative or mixed design. The mixed studies supported their qualitative data and conclusions with quantitative data, thus, it was deemed reasonable to consider the quantitative data in the study as representative of the general conclusions drawn by the authors. Studies ranged from university to elementary level. Typically, two dependent variables were considered, student achievement and attitude toward learning. Student achievement was the primary concern since it was

Table 3

Summary of Study Characteristics and Results

		Research design						Student achievement				Student attitude				Study quality		
Author, year	*n*	Univ	HS	MS	Elem	Control group	Single group	Measurement	Improvement	Sig.*	SMDES	Measurement	Improvement	Sig.*	SMDES	High	Med	Low
Roselli & Brophy (2006)	300	X				X	X	Exam	X		.12	Course evaluation	X	X	.08	X		
Yaeger (2002)	150	X				X		Exam	X		.02						X	
Weir (2004)	78	X				X		Exam	X		.42	Survey	X		.17	X		
Dally & Zhang (1993)	37	X					X	Instructor perception	X			Instructor perception	X					X
Marra et al. (2000)	53	X					X	Perry scheme	X	X	.65					X		
Dunlap (2005)	31	X					X					Self-efficacy scale	X	X	5.00		X	
Irwin (2005)	139		X			X		Exam	X	X	.65					X		
Griffith (2005)	504		X			X						Survey	X	X	.23			X
Cantrell et al. (2006)	434		X			X		Exam	X							X		
Rogers (2005)	62		X			X						Instructor perception	X		.70		X	
Ricks (2006)	131			X			X	Exam	X	X	2.08	Survey	X	X	1.02	X		
Romero et al. (2006)	25				X		X	Instructor perception	X			Instructor perception	X				X	
Lentz & Boe (2004)	25				X		X	Instructor perception	X			Instructor perception	X				X	

* $p < .05$

considered a measurement of student learning. Attitude toward learning was of interest since the field of education generally recognizes a relationship between student attitude toward learning and student learning. As articulated in a National Academy of Engineering publication (Gamire & Pearson, 2006),

> The committee does not consider attitude to be a cognitive dimension in the same way knowledge, capability, and critical thinking and decision making are. However, a person's attitude toward technology can provide a context for interpreting the results of an assessment. In other words, what a person knows—or does not know—about a subject can sometimes be correlated with his or her attitude toward that subject. (p. 3)

This importance of student attitude toward learning is also evident in the literature as 9 of the 13 studies considered for this integrative review measured attitude toward learning as an outcome.

Study quality was rated as a composite consideration of internal and external validity. A typical "lower" quality study used instructor perceptions as their measurement. Lower quality studies had multiple internal validity issues such as Rogers (2005) who drew comparisons between Project Lead the Way teachers (PLTW) and non-PLTW technology teachers. His conclusions on pre-engineering assume that PLTW teachers are teaching engineering and non-PLTW teachers are not. This may generally be true, but the assumption was not substantiated by data and was, therefore, suspect. Yeager (2002) used a control and experimental group of self-selected engineering majors. This study was rated lower in quality due to a threat of internal validity, specifically, history and differential selection. Students in the experimental group not only experience the intervention, but were required to attend class for 25% more time than their counterparts in the control group. Two sections of the course were taught and students elected to participate in either section, knowing the treatment required additional time, thus, an argument could be made that sections were not similar at the onset of this study.

Student Achievement

Ten studies measured student achievement, and each indicated positive change, refer to Table 3. This change was typically measured by an exam, generally, a semester exam on the college level or a unit exam in secondary education. Exams were typically multiple choice. Some were developed specifically for the research project, while others were traditionally used in the course. Marra and colleaegues (2000) differed from the other studies because she used the Perry Scheme as a measure of achievement:

> William G. Perry developed a quantifiable measure of intellectual development from studies of Harvard and Radcliffe college students in the 1960s. The Perry model has a range of “positions” from 1 to 9, each representing an increasingly complex and mature level of intellectual development. Several Perry positions are relevant to college student development and to first-year students in particular. (p. 39)

One study at the university level and both studies at the elementary level used instructor perception of student improvement as their sole indicator of achievement. While instructor perception is a bias and subjective measure, it may be appropriate for consideration on the elementary level as a reasonable means of measuring student understanding of content material, thus, these elementary studies were rated with a medium quality. Instructor perception on the University level is not the most appropriate measure of achievement and, therefore, Dally’s 1993 study was rated relatively low on the quality scale.

A typical study at the college level used either multiple sections as control and treatment groups or previous year semester test results as control and current semester test results as the experimental group. Notable results emerged from two of the four high school research studies which considered student achievement. Irwin (2005) conducted a high quality study with control and experimental groups and delivered a problem based learning activity including three units over an eight week span. Results were statistically significant ($p < 0.05$) with an standardized mean difference effect size of 0.65, considered medium (Cohen, 2001, p. 222). Cantrell and colleagues (2006) conducted a study wherein engineering design challenge activities supplemented the standard curriculum, and student performance was compared to statewide statistics on the standardized tests. This study concluded engineering modules reduced achievement gaps of most ethnic minority groups. Weir (2004) also differentiated her data based on student groups, but she considered an academic top half and an academic lower half in a university engineering course. Her conclusion was that the upper half improved significantly ($p < 0.05$), while the lower half was not significantly ($p > 0.10$) different between the pre and posttest measures.

In general, these data suggest that learning techniques associated with engineering design challenges are successful in improving student achievement. Specifically, Weir (2004) and Cantrell and colleagues (2006) presented conflicting results. The Cantrell et al. study represented a collaborative effort between the College of Education and the College of Engineering at the University of Nevada and middle school science teachers. The partnership program administered during the 2005 school year was entitled Teachers Integrating Engineering into Science. Three units of instruction were collaboratively developed which included web-based simulation activities, lesson plans, a design project, and assessment. Results of the assessment were disaggregated by gender ethnicity, special education and socioeconomic level. The study sample included 434 eighth-grade student participants in approximately 30 classrooms and compared mean scores to similar groups from the previous year. This study concluded that typically low achieving students, disaggregated by their ethnic minority status, improved more dramatically than did typically high achieving students. The study conclusion was that engineering design challenges generally reduce the achievement gap. In contrast, Weir concluded that engineering challenges extend the achievement gap by improving the academically successful students disproportionately to lower achieving students. Weir developed an "active-based-learning curricula," which was implemented in an experimental control treatment design on the undergraduate level in transportation engineering. Active learning strategies implemented in the experimental group included questioning, problem solving in individual and group settings as well as discussions to apply knowledge to "real-life" problems. The control group course was taught one year prior to the treatment group course, consisting of 78 junior and senior students at Worcester Polytechnic Institute (WPI).

Student Attitude Toward Learning

Nine of the 13 studies considered attitudinal measures (refer to Table 3). The measures ranged from motivation, perception of value, enthusiasm, enjoyment, self efficacy to teamwork. This broad range of meanings, while differing, all refer to a student’s perceived experience in the classroom and hold the potential to reflect a positive improvement. Of the nine studies considering attitude, all showed some level of improvement with four studies indicating statistically significant improvement at the $p < 0.05$ level. Standardized mean difference effect sizes ranging from 0.08 to 5.00. Attitude effects do not appear to covary with study quality since high-quality studies have both high and low effects.

Typical attitudinal measures were either: researcher generated survey questionnaires with no mention of validation or instructor (teacher) perceptions. One study used the course evaluations as an instrument. This course evaluation, while a standardized measurement instrument, was not developed for the purpose of measuring student attitude. Rather, its purpose is a rating of the quality of instruction. While each study did show improved attitude, conclusions drawn must be conservative. Low effect sizes may be artificially low as a result of inappropriate instruments, not designed to answer the question at hand. Large effect sizes may be over-inflated, again, as a result of poorly constructed instruments. Thus, for the purpose of this study, an instrument was administered which had been developed and validated, specifically, for measuring attitude in high school students.

Need for Further Research

This integrative review, generally, concludes approaches to teaching which include application of an engineering design challenge increase student learning and improve student attitudes regarding learning. This conclusion is based on a representative sample which surveys elementary through university studies. One area of contention yet to be resolved is whether engineering design challenges work equally well with successful and struggling learners.

Technology education has typically been a curricular area where a broad range of students can be successful, from the academically gifted students to the academically challenged students. Many experts in the field are voicing stronger concerns that engineering should be a more integral part of technology education. With this infusion of engineering into technology education, an increasingly diverse group of student clientele will be enrolling in these courses. Engineering, traditionally reserved for the academically elite students, will be intersecting a broad cross section of the general education populace. This interface necessarily includes a subset of students who are challenged by traditionally “academic” material. The emergent question to be addressed in this study was: do high school students of varying academic aptitudes experience success equally as a result of an engineering design challenge?

CHAPTER III

METHODOLOGY

The significance of this study was to build a research body of evidence regarding student participation in an engineering design challenge. Experimental research has shown that students, generally, improve as measured by achievement and attitude toward learning as a result of engineering design activities more dramatically than without these activities. This study seeks to shed light on the relationship between achievement during an engineering design challenge and mental motivation as predicted by a student's academic background. The practical significance of this study was twofold. First, technology education students may not all benefit equally from an introduction of engineering concepts through an engineering design challenge. Unfortunately, as discussed in the literature review, current literature was sparse and ambiguous on this topic. Second, students in engineering education courses differ in academic backgrounds. An understanding of the relationship between student background and their potential growth during an engineering design challenge was beneficial in developing a strong educational experience for both fields.

"It is important to realize that not all research involves experiments; much of the research in some areas of psychology involves measuring differences between groups that were not created by the researcher" (Cohen, 2001, p. 8). The purpose of this correlational research study was to determine if students' academic success was correlated with: (a) a change in achievement during an engineering design challenge, and (b) a change in mental motivation toward solving problems and critical thinking during an engineering design challenge.

The criteria variables for this study were a student's change in cognitive achievement (specific to the course in study) and motivation to apply critical thinking and reasoning skills to solve problems. This change was established by measurements on three occasions during the school year. An achievement test was developed in cooperation with the course instructors based on course goals and objectives. The need for a valid and reliable instrument was of paramount importance, and, therefore, a six-step procedure for criterion referenced tests was adopted as presented by Schloss and Smith (1999). The criterion variable of mental motivation to apply a student's critical thinking and reasoning skills was measured by a professionally developed instrument known as the California Measure of Mental Motivation (CM3). This instrument has been validated for high school students and was considered reliable (Insight Assessment, 2007b).

Longitudinal multilevel analysis techniques were employed to evaluate potential correlations between the predictor variables and the outcome variables. "The term 'multilevel' refers to a hierarchical or nested data structure, usually people within organizational groups, but the nesting may also consist of repeated measures within people, or respondents within clusters as in clusters sampling" (Hox, 2002, p. ix). This multilevel analysis modeling facilitated the longitudinal repeated measures design. It also controlled for differences between course sections and enabled the predictors to be differentiated by subject area.

Research Hypotheses

Research (Cantrell et al., 2006; Weir, 2004) suggests conflicting evidence regarding a relationship between academic success and the efficacy of an engineering design challenge. Two null hypotheses were developed regarding the relationship between engineering design challenge efficacy and a student's academic background. The null hypotheses were that any correlation that existed between a student's academic background and their change in achievement or mental motivation throughout the school year was due to chance.

Research Question

A survey of the related literature has indicated that engineering design challenges are successful. Available evidence does not address definitively the potential relationship between a student's general academic success and their growth during an engineering design challenge. The emergent broad research question for this study was: do high school students of varying academic aptitudes experience success equally as a result of an engineering design challenge? More specifically, this study had two main research questions: (a) Does a general indicator of previous academic success serve as a significant predictor of student learning as measured by an achievement test, and (b) does student motivation for solving problems and applying critical reasoning skills correlate with a general indicator of previous academic success?

Instructional Setting

A high school classroom has been identified in which a physics teacher partners with a technology education teacher to infuse and apply engineering concepts in a course called, "Industry and Engineering Systems." This junior level, high school course includes an academically diverse array of students and a semester long engineering design challenge. In the fall term, students participated in hands-on learning experiences which represent an intersection of technology education and applied physics, for example; concepts such as motion, forces, electricity, magnetism and simple machines, as well as welding, machining, mechanical fasteners, cutting and bending metals. During the spring term, students applied these concepts in design teams to the Electrathon America challenge (Appendix E). The spring term culminated with fabrication, testing, redesign and, finally, racing the student designed and built electric cars.

Classroom lecture, activities and lessons modeled infusion of engineering concepts into a technology education classroom. Typical technology education projects included magnetic levitation cars, Lego/solar cars, gearing systems, and electric motors. These projects facilitated the marriage of practical application with engineering. The instructor's classroom goals included encouraging the students to see the application of math, science, language arts to hands-on projects and learning basic engineering concepts (M. Brewer, personal communication, December 1, 2006). As stated in the syllabus, the course is comprised of a science component and industrial technology component:

> SCIENCE: Physics itself is the study of how things around us in the real world work and why they do the things that they do. Engineering is largely the application of physics. The course will use mostly hands-on activities to explore

> and discover the major concept of physics dealing with motion, forces (such as gravity), and simple machines. We will also study areas of electricity, heat, magnetism, aerodynamics, and air pressure. This course will introduce many concepts of engineering and the designing of systems. The student will learn mostly by doing small group projects or labs. We will then apply this knowledge to real life activities.
>
> INDUSTRIAL TECHNOLOGY: In this part of the course, we will be using mostly metals but to some degree all of the technology lab facilities here at Porter Valley, including mechanics, electronics, drafting and woods. We will learn to use these facilities to design, construct, and test some of our major projects. Emphasis will be placed upon machine and tool safety, individual skill building, proper tool selection and setup, and operation. The labs will provide a bridge between what we learn in the classroom to practical applications in a real world setting. We will apply technology, and the skills we have learned in math, science and communication to several major projects.

During the fall 2007 semester, teachings provided a foundational knowledgebase for the spring 2008 term. In early January 2008, students started the engineering design challenge with a $1/10^{th}$ scale model of an electric car and driver. Teams of 2-6 students designed, modeled and built their Electrathon vehicle. Constraints were imposed by the Electrathon rule book and local facilities. Designs were optimized for minimal weight, tire scrub, air resistance, and other characteristics. Predictive analysis was incorporated into the modeling in the form of model car wind tunnel testing, gear ratio calculation, power demand calculation, and battery life to distance traveled ratios. Understanding these parameters was developed in the fall term by building and testing smaller projects such as magnetic levitation cars and calculating horsepower capacity of a student built electric motor.

Participating Instructors

For purposes of anonymity, the participating teachers, district, and students will be referred to with pseudonyms. Moe Brewer has been designing, building and racing vehicles with students for over 14 years while Oly Rivet has been teaching for 10 years. Mr. Brewer and Mr. Rivet usually have over 75 students enrolled in the Industry and Engineering Systems courses in which they teach students to think, problem solve, and work as teams to design, build, modify, maintain, and race an Electrathon vehicle.

Mr. Brewer is a certified teacher in his state with a physics, math and chemistry background. Mr. Rivet is a certified career and technical education teacher endorsed in manufacturing technology. They teach courses at Porter Valley High School, which served approximately 1,500 students in grades 9-12.

Study Participants

Of critical importance to generalizability is sample size. In the two sections that participated in the study, a total of 53 11th-grade students made up the sample. These students represented a typical classroom in the northwestern states including students who are academically high achievers and students who struggle with their performance in school. According to the instructors, students who elected to take this class, generally, have one of two motivations: they were headed to college to be engineers or were students having failed freshmen and/or sophomore science and needed a credit to graduate. Thus, the academic diversity ensured this study had the potential to discover trends and correlations across a broad range of student achievers.

Institutional Review Board

The institutional review board was apprised of this study and approved the study as exempt #2, protocol number 1838 (Appendix F). The school district provided a written letter of support for this study (Appendix G). Letters of information for the participating teachers may be found in Appendix H and a letter for students and parents in Appendix I regarding the pilot achievement test. The school district used their letterhead to mail the formal letter of information to parents for this study (Appendix J).

Data Collection Procedures

Overview

In order to address the research questions, a correlational study was conducted in which data were gathered on student achievement and mental motivation during the course. Quantitative data were gathered on three occasions, October, December, and April. Multiple measurements facilitated analysis of changes during the student experience, as well as establishing trends. The multiple measurements lent power to the statistical techniques employed and strengthened conclusions based on data. Trends and changes during the year were compared statistically to a general indicator of each student's academic success. This indicator was an analysis of the junior students' grade point average which includes math, science, and literature/reading scores (communications).

"Achievement tests are designed to provide information about how well test takers have learned what they have been taught in school" (Gay & Airasian, 2000, p. 154). The United States Department of Education (2008) recognized the importance of student achievement in the organization's mission statement by having stated, "ED's [U.S. Department of Education's] mission is to promote student achievement …" Achievement was measured by a test developed in partnership between the researcher and the classroom teachers. This test was based, specifically, on the goals and objectives of the course, and test items were drawn from validated test banks which included state departments of education and textbook publishers. A pilot test was generated, administered, and results analyzed to ensure validity and reliability of the instrument. Three similar variations of this multiple choice test were created from the pilot test and utilized during the study.

Mental disposition assessment complements achievement testing since it measured the students' motivation to attempt to solve a problem by thinking critically about issues. Mental motivation measurements were made using the CM3. An overview may found in Appendix K. The CM3 test assessed a student's motivation to apply critical thinking and reasoning skills for decision making or problem solving. Importantly, this test has been validated for use with high school students and is considered reliable (Appendix L).

Measures of achievement and mental motivation provided an opportunity to understand the extent to which students were motivated to solve complex problems and think critically during engineering design challenges. This understanding of the correlation between a student's academic history and growth during an engineering design challenge complements the growing literary body which indicates that engineering design challenges are successful but failed to identify a student's academic background as a potential predictor of growth. This repeated measures design allowed the researcher to identify cognitive growth in terms of achievement and affective growth related to mental motivation for the purpose of correlation with a general indication of a student's academic history.

Based on the earlier definition of an engineering design challenge, an assessment rubric was developed and utilized to quantify the extent to which characteristics of an engineering design challenge have been implemented by the instructors during this course, thus, differentiating it from other problem solving methodologies. Each site visit during the school year included administration of achievement and mental motivation tests in addition to observation and assessment of the learning environment. The observations served to extend the generalizability of this research by ensuring a rich description of the teaching methods and content. Engineering design challenges may take many forms, varying by instructor, classroom, and age group. In order to ensure generalizability, thorough documentation was deemed necessary to describe the specific content and methods of delivery.

Instrumentation

Correlational studies are comprised of predictors and outcome variables. "A correlation coefficient is a precise mathematical expression of the types of relationships between variables…. In other words, the coefficient indicates the extent to which scores on one variable co-vary with scores on another variable” (Gall et al., 1999, p. 212). Predictor variables in this study were scores on grade point averages in math, science and reading/literature. Outcome or criterion variables were the changes in achievement measured by a multiple choice test and motivation to apply critical thinking skills as measured by the CM3.

Predictor–Academic Performance

Student grade point average was used as a general indicator of student academic performance. The school district personnel promptly delivered transcripts for 52 of the 53 participants. The remaining transcript was unavailable to the district because the student had transferred, and the original school had not complied with district requests for the transcript. Participants with predictor data were removed from analysis, as explained by Hox (2002), “If explanatory variables are missing, the usual treatment is again to remove the case completely from the analysis” (p. 95). Grade point averages were computed for each student’s freshmen and sophomore years which represented a cumulative grade point. Additionally, classes recognized for graduation purposes as math, science and communication, were tabulated and averages computed.

Outcome–Cognitive Achievement

Pilot test development and administration. Criterion variables included achievement and motivation to apply critical reasoning skills. A suitable test had not been developed for measuring the extent to which the goals and objectives of this course have been reached. Therefore, an instrument was developed and pilot tested. Schloss and

Smith (1999) proposed a six-step methodology for developing and testing an instrument. This method was adapted to develop a cognitive achievement test.

Step one was identifying the skills being studied. The researcher, in collaboration with the course instructors, had identified skills taught which relate strongly to engineering, particularly statics and dynamics courses in preparation for application to an engineering design challenge. Triangulation of findings was done through examination of course material including syllabus, handouts, worksheets, and researcher observation.

Step two involved enumerating skills wherein the skills identified were broken down into smaller elements which could be measured. The researcher differentiated between conceptual and mathematical understanding of the engineering related materials.

Step three included establishing test specification, skills, and subskills that were identified, specifically, for this test and a multiple choice format was selected. The pilot test, as suggested by one of the course instructors, has been developed primarily to measure a conceptual understanding to minimize ambiguity with questions which required conceptual and mathematical understanding.

In step four, test items were developed. In order to reduce bias and increase reliability, test items were selected from external sources rather than researcher developed. These external sources included released test items from state departments of education from a comprehensive survey of 50 states. The other source of test items was publishers of texts pertaining to technology education, engineering and physics. Many of these publishers supply test banks to teachers for classroom use matching the needs for this study.

Step five focused on a scoring procedure. As a result of test specification, step three, a multiple choice test, includes an answer key. The answer key was researcher generated based on the test sources and course instructor verified.

The final step, six, included evaluating reliability and validity. A pilot test was assembled and administered to students during the 2006-2007 spring term near the conclusion of the school year. These pilot students were expected to be comparable to the students participating in the main study, since they were in the same courses with the same instructors. The pilot test was administered in the late spring just as the posttest was in April of the 2007-2008 school year. A Kuder-Richardson 20 (KR-20) statistical analysis was used to refine the pilot test and develop a final version of the exam. As explained by Gall and colleagues (1999):

> The KR-20 formula is a method of calculating the reliability of a measure containing items that are scored dichotomously (e.g., correct-incorrect). A high reliability coefficient (i.e., approaching 1.00) indicates item consistency, meaning that individuals who choose one answer to some items tend to choose the same answer to other items. Correlation coefficients between .73 and .86 indicate that the course examinations have good but not perfect reliability in terms of the consistency with which they measure students' course-related understanding and ability. (p. 260)

For purposes of this study, .80 as identified by Gall and colleagues as “good” was used as a target benchmark target during the test development. Content validity was addressed as skill areas were represented by multiple questions, and a statistical assessment of the variance among set questions was computed. Also, one of the course instructors, with 14 years of classroom experience, verified the test items represented the teaching goals and objectives. The concurrent validity of the pilot test was established by course instructors’ observation of a correlation between pilot test scores and observed student performance during the school year. Refer to Appendix M for the pilot test.

Achievement test development and administration. From the pilot test, three similar versions were developed (refer to Appendix N for version A, Appendix O for version B, and Appendix P for version C). Each of these versions has the same test specification, targeting the same skills. Each test version has a combination of alternate questions, modified questions and a few repeated questions. Inherent in the fact that the tests are different, student mean scores varied slightly. To ensure changes over time were student changes rather than instrumentation changes, a randomized test administration was followed. During each test administration, one-third of the students received each version of the test. At the conclusion of the term, all students had taken each test version, but not in the same order. Students were randomly assigned to groups for the purposes of test taking. Each group took a different version of the exam during each testing session as shown in Table 4.

The 43-item pilot test was analyzed using two measures, the Kuder-Richardson-20 (KR-20) and an indication of the relative difficulty of each item. The test was reduced from 43 pilot questions to a 30-question test and became version A. The final KR-20 for

Table 4

Procedures for Administrating Achievement Test

	Student group 1			Student group 2			Student group 3		
Test version	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
A	x					x		x	
B		x		x					x
C			x		x		x		

version A was 0.781. From version A, additional questions were developed to form versions B and C that were considered comparable. These additional questions fell into one of three categories: original, modified and repeated. Original questions were utilized as found from the test banks. Modified questions were based on original questions but modified from their original form for one of two reasons: (a) to make them relevant, and (b) to use them again in another version. A typical example of a question modified to be more relevant dealt with distance, velocity, and rate calculations and was changed to include locations proximate to the research location. Another example of a typical modified question would be one that solicited students to identify which gear ratio provides the most torque changed to most speed or least speed. In some instances, questions were repeated verbatim since comparable questions were not located, and modifying the format was impractical. Table 5 shows 90 questions distributed among the three versions. Sixty-six items were original as found in standardized test sources. Thirteen questions were modified and reused in another version, and a total of 11 questions were repeated.

Graphics accompanied some of the questions, and the test versions have a consistent proportion of questions with and without graphics. Most questions provided

Table 5

Origination of Achievement Instrument Items

Test version	Original	Modified	Repeated
A	28	2	0
B	21	4	5
C	17	7	6

four response options for students. While a few questions offered three responses, the distribution of these questions was also held constant across the test versions. Most questions targeted a conceptual understanding of the material presented while a small percentage included an applied mathematical component. These applied questions were evenly distributed across test versions. The table in Appendix Q identifies the six skill areas targeted in this course, test item origin, and references comparable questions across each test version.

Outcome–Mental Motivation

The second outcome variable was motivation to apply critical thinking and reasoning skills to solve problems. The Mental Measurements Yearbook was used as a guide for identifying motivational measurement instruments. Search criteria included critical thinking and reasoning, and motivation. The population was limited to high school students. The California Critical Thinking Dispositions Inventory (CCTDI) was narrowed from a list of potential tests. After an extended conversation with a representative of Insight Assessment—The California Academic Press, the CM3 was identified as more appropriate for high school students. The CM3 measures a student's motivation to apply critical thinking skills and reasoning to solve problems. Five areas were assessed as explained by Insight Assessment:

1. Mental Focus/Self-Regulation: The person scoring high in mental focus is diligent, focused, systematic, task-oriented, organized and clear-headed.

2. Learning Orientation: A person scoring high in learning orientation strives to learn for learning's sake; they value the learning process as a means to accomplish mastery over a task. These individuals are eager to engage in challenging activities, they value information and evidence gathering, they

recognize the importance of giving reasons to support a position, and they take an active interest and are engaged in school.

3. Creative Problem Solving: The person scoring high in creative problem solving is intellectually curious, creative, has a preference for challenging and complicated activities, is imaginative, ingenious, and artistic.

4. Cognitive Integrity: Individuals scoring high in cognitive integrity are motivated to use their thinking skills. They are positively disposed toward truth seeking and open-mindedness.

5. Scholarly Rigor: Scholarly Rigor is the disposition to work hard to interpret and achieve a deeper understanding of complex or abstract material. A person with a high score on this scale exhibits a strong positive disposition toward scholarly rigor would not to put off by the need to read a difficult text or to analyze complicated situations or problems. (Insight Assessment, 2007c)

This assessment of motivation to apply critical thinking skills was complementary to the achievement test. The achievement test measured a student's ability to apply conceptual material learned in class while the mental motivation test measured students' inclination toward attempting to solve the problems. In a conversation regarding student growth and development during the engineering design challenge, one of the course instructors commented that often students describe to him their discovery of "relevance." The students realized the importance of theoretical principles since they related to practical application. This discovery on the students' behalf was combined with enthusiasm and an excitement of learning and thinking, according to the instructor. In addition to measuring cognitive growth, a student's motivation to learn and apply newly learned concepts was pertinent to this study. The importance of this motivation was that it represents a development in the student. A student who was motivated to think critically would be inclined to perform better on future achievement tests because they are applying their knowledge base and exploring new academic material (Participating instructor, M.

Brewer, personal communication, December 1, 2006).

Validity and reliability of the CM3 instrument are critical to this study (see sample CM3 items in Appendix R). Reliability has been computed using the Cronbach's alpha and published by Insight Assessment, "The internal consistency of scores obtained using the CM3 was evaluated using Cronbach's alpha coefficient. In the three validations studies, alpha coefficients ranged as follows [refer to Table 6]" (2007, p. 27). In addition to reliability assessments, the CM3 has been studied for its external validity, predictive validity and discriminant validity, published by Insight Assessment:

> Three forms of validity studies were performed. First, the CM3 scales were investigated in relation to previously validated measures of student motivation and behavior (external validity). Second, the hypothesis that the disposition toward CT [Critical Thinking] is positively related to academic achievement was tested by examining correlations between the CM3 scales and students' standardized test scores and GPA (predictive validity). Third, discriminant validity of the CM3 was demonstrated using correlations with the Marlowe-Crowne Social Desirability Index. (Insight Assessment, 2007c, p. 27)

Evidence of Engineering Design

Application of the engineering design process was measured through a

Table 6

Cronbach's Alpha Coefficient for CM3

Focus area	Cronbach's alpha
Learning orientation	.79 - .83
Creative problem-solving	.70 - .77
Mental focus	.79 - .83
Cognitive integrity	.53 - .63
Scholarly rigor	NA

(Insight Assessment, 2007c, p. 27)

quantitative observation matrix. “Quantitative observations are ways of measuring classroom events, behaviors, and objects” (Glickman et al., 2004, p. 260). This quantitative matrix highlighted the criteria established for this study as synthesized from Dym et al. (2005), Eide, Jenison, Mashaw, and North (1998) and Edie et al. (2001). This model included a focus on six main engineering design elements:

1. Problem Definition
2. Solutions
3. Analysis / Modeling
4. Experimentation
5. Decision Making
6. Teamwork.

The matrix observation form (Appendix S) includes a rubric for quantification of the extent to which these elements were present in the classroom learning environment. The rubric form (Appendix T) was adopted from earlier work of Davis et al. (2002) in which the authors focused on program assessment and accountability. Davis’ work paralleled in content and purpose the evaluation goal of this study which was to assess the extent engineering design was facilitated in the classroom. Their rubric was modified and adapted to fit the specific content of this study and the high school classroom.

Each lesson observed during the fall term was subject to evaluation with the observation matrix and data serves as evidence of the extent to which engineering design was being utilized in the classroom supporting the goals and objectives of this study. Qualitative notes accompany each observation, thus, providing evidence for the narrative component of this study which highlights classroom pedagogy.

Contextualizing the Research Setting

Based on the nature of an engineering design challenge, variance can be expected in content and delivery between instructors and classes. In order to extend generalizability, a series of observations were planned. During these observations, qualitative data served to aid in triangulation of the quantitative matrix data.

> Participant observation involves establishing rapport in a new community; learning to act so that people go about their business as usual when you show up; and removing yourself every day from cultural immersion so you can intellectualize what you've learned, put it into perspective, and write about it convincingly. (Bernard, 1994, p. 137)

In order to most effectively establish this rapport, each site visit was planned for two weeks duration. Gaining entry to the research site means study participants forget a researcher is present and “let down their guard” (Gans, 1968). After entry has been gained, test administration and observations were conducted. Documents were gathered including lesson plans, student handouts, and student generated materials. These documents and observations served to present a comprehensive description of the research site, teaching method employed, and content delivery. This descriptive data facilitates replication and extends generalization by situating quantitative research findings within the research setting.

Data Analysis

Analysis strategies were employed, as suggested by Creswell (1998), which included a general review of all information, feedback from informants, data reduction, and categorization. Data analysis was conducted as conceptualized by Creswell (1998) as a “spiral” (p. 143). Data collection lead to data management, reading and memoing, describing, classifying and interpreting and finally representing. This iterative process evolved as the study progressed thus shaping the data collection and being shaped by data which were collected and interpreted.

Data collection included journaling observations during instructor lectures where the researcher was seated in a student desk near the back corner of the classroom. The researcher took an active role in moving among groups of students as they worked on projects in the lab settings. Quotes, as well as observations, were documented. The researcher regularly asked the students what they were doing and why, probing for a verbalized explanation in student language. Care was taken to minimize leading questions from the dialog, and limit interactions to what became typical questions, “how and why.” Students grew accustomed to this regular inquiry and would anticipate the questions before the researcher would ask. This regular dialog became a natural interaction between the researcher and students.

Observational journal data were voluminous. At the conclusion of each day of observation, data were reviewed. A typed summary was created to synthesize the daily routines which included a reflective portion where the memoing process, as described by Creswell, was implemented. Observations and memoing were recorded in a field notebook in the form of descriptive and reflective notes, described by Creswell (1998):

> “Descriptive notes” where the researcher records a description of the activities and a drawing of the physical setting. Moreover, the researcher provides “reflective notes”—notes about the process, reflection on activities, and summary conclusions about the activities for later theme development. (p. 128)

These summaries served to maintain the iterative nature between observation and analysis which is foundational to qualitative inquiry.

Documents were collected from the students and teachers. All students were required by their instructors to journal as a part of their daily routine. As students completed assignments, they would submit a report for evaluation to the instructors. This report included their daily journal, student data collected, analysis completed (typically in the form of a worksheet) and a written reflective component in which students were asked to describe the process and what they could have improved for next time. Data were scanned digitally and archived from student reports for later analysis.

Data analysis continued with “getting a sense of the whole database” (Creswell, 1998, p. 143). All data were reviewed multiple times to prepare for classifying. Data categorization followed a constant comparative strategy as outlined by Bogdan and Biklen (1982), Stainback and Stainback (1988), and Taylor and Bogdan (1998). This strategy involved a six-step methodology wherein categories were created by important issues or recurring events. Additional data was collected to provide many examples for each category. Categories were dynamic and flexible as new data shaped the description. Patterns and relationships were identified and additional data collection served to refine findings.

Data coding and themes generation was, in part, established a priori to parallel the six elements of engineering design for this study. These six elements had emerged from the literature review and were implemented as a primarily focus of the professional development. Theme generation was not limited to these six elements and as data were reviewed, additional emergent themes were established.

Verification

"Qualitative researchers strive for 'understanding,' that deep structure of knowledge that comes from visiting personally with informants, spending extensive time in the field, and probing to obtain detailed meanings" (Creswell, 1998, p. 193). Verification that data were collected and interpreted appropriately was critical to the quality of this study. As Eisner (1991) suggested, "We seek a confluence of evidence that breeds credibility, that allows us to feel confidence about our observations, interpretations, and conclusions" (p. 110).

Multiple procedures of verification were followed in this study. Creswell (1998) suggested engaging in a minimum of two of eight procedures presented. For purposes of verification in this study, the researcher has utilized five procedures: prolonged engagement in the field; triangulation; clarifying researcher bias; member checks; and rich, thick description. The researcher has made five site visits, four of which spanned a total of six weeks and included observation of the interactions between the participating teachers and their students. This extended series of observations provided the researcher with data saturation and ensured multiple observations for each theme established. Triangulation was addressed through connecting gathered observations, student generated documents, teacher generated documents, and informal interviews which spanned 53 students in two sections of the classes participating. Researcher bias was briefly presented in the findings section prior to describing the results so that the reader may understand how the researcher's background might influence the interpretation and approach. Member checks were conducted through formal meetings with the participating instructors scheduled during each of the four observational visits. The entire qualitative findings section was presented to the participating teachers for feedback and corrections. As noted by Lincoln and Guba (1985), member checking was “the most critical technique for establishing credibility” (p. 314). Rich, thick descriptions presented in the results section which “…allows the reader to make decisions regarding transferability” (Creswell, 1998, p. 203).

Professional Development

Two experienced teachers participated in this study by allowing the researcher to measure changes in their students. These teachers represent diverse backgrounds in a dynamic team teaching environment. These teachers teach a course entitled, “Industry & Engineering Systems,” which spans two periods. In this course, students receive two course credits—an industrial technology credit and a science credit.

In preparation for the research study, both teachers agreed to participate in professional development on infusing engineering design into their classrooms. The purpose of the researcher lead professional development was not to make drastic changes in the existing curriculum and pedagogy. Instead, a collaborative professional development was designed and conducted to facilitate the application of the engineering design elements established for this study through existing classroom opportunities.

A three day professional development was conducted with the teachers late in the summer of 2007 (Agenda found in Appendix U, Objectives found in Appendix V).

During the design phase of this professional development, it was noted that:

> [Teacher] ... change requires multiple opportunities to learn, to practice, to interact using, and to reinforce new behaviors. Thus, although a single workshop may be a good kick-off for learning and can result in new knowledge or awareness on the part of participants, additional opportunities are needed for long-lasting change. (Loucks-Horsley, Hewson, Love, & Stiles, 1998, p. 93)

Additional opportunities were planned to support the implementation and refinement of the engineering design elements at the research site. "...Teachers acquire and use new skills more readily when there is follow-up into their own classrooms" (Glickman et al., 2004, p. 372). To provide this follow-up, classroom observation, and feedback focused on the implementation of engineering design conducted during each site visit. The site visit included informal and formal follow-up regarding the appropriate application of engineering design in the classroom. A three stage model of professional development was utilized, as presented by Glickman, which included orientation, integration, and refinement (Glickman et al.).

Orientation

The orientation stage was initiated with greetings and a tour of the facility. The researcher established the relevance of, and need for, technological literacy, as paralleled in the literature review. Next, the orientation phase focused on comparing and contrasting the Standards for Technological Literacy design process with the engineering design process. In this dialog, the means by which the engineering design process was established for the purpose of this study were discussed, rooted in the foundation of Eide and Dym. The orientation phase concluded with a case study and used Dr. Mark

Tufenkjian's design challenge of a penetrometer calibration test trench (personal communication, August 9, 2007). This design challenge presented an open-ended problem in which a solution was established that hinged on the control of two pertinent variables in sand deposition. The key theme of this case, for purposes of professional development, was to encourage the teachers to consider their design challenge in terms of a limited number of key variables which students can measure and manipulate. Three overarching themes of the orientation stage included establishing the benefits of participating, responsibilities of each party involved and acknowledging personal concerns of the participating teachers.

Integration

The penetrometer calibration design challenge set a foundation for the integration phase since it established an analogy to the small design challenges in the fall and the large scale electric car design challenge in the spring. In this stage of professional development, the researcher presented an expanded explanation of the element of engineering design including:

1. Problem Definition
2. Solutions
3. Analysis / Modeling
4. Experimentation
5. Decision Making
6. Teamwork.

A professional development package was created highlighting these six elements and associating detailed descriptions in reference texts that accompanied the overview (refer to Table 7). Four texts were chosen since they provided detailed explanation of specific

Table 7

Engineering Design Process Reference

Engineering design	Detailed descriptions
Problem definition	
Questioning	Engineering design, Dym and Little (2004), page 17-21
Constraints	Engineering design, Dym and Little (2004), page 17-21
Evaluation criteria	Engineering design, Dym and Little (2004), page 17-21
Solutions	Engineering design, Dym and Little (2004), page 29-30, 98-108
Research existing	Engineering your future, Gomez, page 335
Brainstorm alternative	Engineering your future, Gomez, page 332-338
Analysis/modeling	
Prediction	Engineering fundamentals and problem solving, Eide, page 69, 83
Uncertainty	Engineering design thinking, teaching, and learning, Dym et al. (2005), page 106
Estimation	Engineering design thinking, teaching, and learning, Dym et al. (2005), page 106
Experimentation	
Based on analysis	Engineering design thinking, teaching, and learning, Dym et al. (2005), page 106
Empirical data gathering	Engineering design thinking, teaching, and learning, Dym et al. (2005), page 106; ZEUS, page 8, 9, 11
Prototyping	Engineering design thinking, teaching, and learning, Dym et al. (2005), page 106
Decision making	Decision matrix: Engineering your future, Gomez, page 361; Engineering design, Dym and Little (2004), page 44; ZEUS, page 7 Functions/means chart: Engineering design, Dym and Little (2004), page 120 Functions/means tree: Engineering design, Dym and Little (2004), page 85 Time line chart: Engineering design, Dym and Little (2004), page 172 Objective tree: Engineering design, Dym and Little (2004), page 58
Evaluation of solutions	Constraints/objectives chart engineering design, Dym, page 110
Optimizing	Modeling example: Energy model, motion model; ZEUS, page 11-12
Teamwork	Team calendar: Engineering design, Dym and Little (2004), page167
Working effectively	Engineering design, Dym and Little (2004), page 32-38 Responsibilities chart: Engineering design, Dym and Little (2004), page164
Communication	Engineering design thinking, teaching, and learning, Dym et al. (2005), page 108

elements of engineering design and examples of classroom applications for the teachers to emulate in their instructional setting:

1. *Engineering Fundamentals and Problem Solving* (Eide, Jenison, Northup, & Mickelson, 2008)
2. *Engineering Design: A Project-Based Introduction* (Dym & Little, 2004)
3. *Engineering Your Future: A Project-Based Introduction to Engineering* (Gomez et al., 2004)
4. *Engineering the Future* (Pierik, 2008)

In addition to the texts, two documents supported the explanation of engineering design and its application in the classroom:

1. Engineering Design Thinking, Teaching, and Learning (Dym et al., 2005)
2. Zero-Emission Utah State Snowmobile (ZEUS; Brown et al., 2007)

The texts and documents were utilized to provide detailed explanation and exemplars for each of the six identified engineering design elements. Table 7 identifies the engineering design elements and references further detail by title, author and page number. This table was a key element in the professional development package accompanying a copy of each text and document for reference at the research site. This material was reviewed with the teachers for the purpose of applying this model to their instructional strategies.

Fall Engineering Design Summary Matrix

A matrix was developed to facilitate identifying how the elements of engineering design were experienced by the students. The matrix was an agreement reached among the teachers and the researcher regarding the implementation of engineering design elements as shown in Appendix W. A summary matrix was created to demonstrate the frequency that each element of the engineering design process was covered in the fall semester (Table 8). In addition to the implementation of engineering design elements, students were required to maintain a design journal with notes from the lectures including relevant science and physics principles.

Table 8

Engineering Design Application Frequency Matrix, Fall 2007

	Lesson/activity				
Engineering design elements	Mag lev	Electric motors	Solar/gearing systems	Lego/ solar car	1/10 scale model
Problem definition					
Questioning				x	x
Constraints	x	x	x	x	x
Evaluation criteria	x	x	x	x	x
Solutions					
Research existing	x	x		x	x
Brainstorm alternative	x	x		x	x
Analysis/modeling					
Prediction	x	x	x	x	x
Uncertainty	x	x	x	x	
Estimation	x		x		x
Experimentation					
Based on analysis	x	x	x	x	x
Empirical data gathering	x	x	x	x	x
Prototyping	x	x		x	x
Decision making					
Evaluation of solutions	x	x	x	x	x
Optimizing	x	x	x	x	x
Teamwork					
Working effectively		x	x	x	x
Communication	x	x	x	x	x

Spring Design Challenge

The spring semester was, initially, approached with the same method as the fall in which the researcher intended to identify how each lesson would fit into the application of the engineering design. The spring semester, however, was presented to the students as a large learning project in which lessons were delivered in a "just-in-time" format and were flexible and dynamic, based on the needs of the students. This lack of formal structure inhibited the systematic identification of fitting the lessons in the engineering design elements and instead, lent itself to a qualitative documentation of how each area would be addressed throughout the semester.

During the professional development, the researcher, in cooperation with both teachers, identified learning experiences planned for the spring during which the elements of engineering design would be applied. This planning process was initiated during the summer of 2007 in the first formal professional development meetings and revised in October and December during refinement meetings as the teachers' understanding of engineering design (and the researcher's understanding of the classroom) evolved. This agreement was not intended to be all encompassing of every learning experience. Rather, it was an overview. The teachers were familiar with the six elements and expressed interest in utilizing these elements during additional appropriate opportunities which may arise. Generally, the instructors followed through with plans made during the professional development and qualitative data were gathered to document the application of engineering design. This data is presented in the findings section for purposes of contextualizing the research setting.

Refinement

As part of Glickman's three-pronged approach to professional development, refinement serves to solidify the key concepts and reinforce their application in the classroom. It also provides a forum for dialog between the practicing teachers and coach. As a component of each site visit, the researcher observed the teachers working with students. Engineering design content and delivery methods were observed, and feedback was provided to the teachers. Some feedback was provided immediately when the opportunity presented itself (i.e., walking from the classroom to the lab or when students were working in the lab and the teacher had a moment). More focused and formal feedback was delivered and discussed in a meeting planned once per visit. Feedback from the teachers was solicited in the form of evaluation forms found in Appendix X. During these more formal meetings, the researcher provided guidance as a coach, but also maintained an atmosphere conducive to discussions regarding how to implement engineering design. In this forum, the researcher attempted to facilitate a collegial atmosphere where both teachers could openly discuss their concerns and critique their efficacy relative to delivering design to their students.

Analysis

Data analysis was conducted using longitudinal multilevel modeling techniques. This analysis allowed multiple predictor variables to be analyzed in this repeated measures design for prediction of student achievement and mental motivation. "…Applications of multilevel models are longitudinal research and growth curve research, where a series of several distinct observations are viewed as nested within individuals…" (Hox, 2002, p. 1). Predictor variables included high school grade point average (general indicator of academic history), time, and section. The main predictors of concern were the grade point averages for each academic area (science, math, and communications). This predictor served as a variable with which a correlation was identified with the outcome variables. The predictor of time was critical since it had three time points, pre (October), mid (December), and post (April). Change in students was expected as a result of time, and, therefore, our knowledge of the time point served to establish a growth trend. While two sections of students have enrolled in this course, membership in a section cannot be assumed as random chance. Scheduling conflicts may have impacted student enrollment rather than random chance alone. The researcher has noted that an advanced math class conflicted with one of the sections of this course. To control for these factors, the section membership was recorded and entered into the model. The ability to control for these differences strengthened the model by reducing variability.

Hox (2002) commented on the application of multilevel analysis in repeated measures designs:

> Longitudinal data, or repeated measures data, can be viewed as multilevel data, with repeated measurements nested within individuals. In its simplest form, this leads to a two-level model, with the series of repeated measures at the lowest level, and the individual persons at the highest level. (p. 73)

In this study, as suggested by Hox, level one is the three time points. Level two is the individual level including three predictor scores (math, science, communications), the class section, achievement scores and mental motivation scores. In the modeling strategy, the power of this statistic was increased by having multiple data collection points rather than only a pre and posttest design (Hox, 2002).

Efforts were made to ensure all students' participating in the study were present during the testing sessions. A 2-week stay at the research site facilitated data gathering from all students. In the rare event that a student was not available during this time, multilevel analysis results were not jeopardized by missing cases. The data available were used and contributed to the model regardless of one or more missing data points. This strength served to ensure a large sample size.

In the modeling process, the main effects of predictors were considered in addition to their interactions with time. Interactions between main effects were analyzed including the effect of academic history and time. Slopes and intercepts of main effects and interactions were interpreted. This analytic modeling strategy facilitated an understanding of relationship between a student's general academic history and changes in achievement and mental motivation during an engineering design challenge.

Summary

As stated by Gall and colleagues (1999):

> Educators hold many beliefs about how the different characteristics of the groups or individuals with whom the work relate to one another. They also are constantly searching for attributes that help them predict the future success of their students, or of individuals for whom they have administrative responsibility. The techniques of correlational research provide a precise means for testing these beliefs and for improving predictions. For these reasons, correlational research plays an important role in the quest to improve the knowledge base upon which educational practice rests. (pp. 220-221)

This correlational study determined the extent to which a student's academic success is correlated with: (a) a change in achievement during an engineering design challenge; and (b) a change in mental motivation toward solving problems and critical thinking during an engineering design challenge. Multiple measurements of achievement and attitude were conducted from October to April and facilitated analysis of trends in student growth. The growth was correlated with a general indication of a student's academic success. Conclusions to the research questions were drawn focused on the efficacy of an engineering design challenge for students who were academically successful and those who were struggling academically.

CHAPTER IV

RESULTS

The purpose of this correlational research study was to determine if academic success is correlated with: (a) student change in achievement during an engineering design challenge, and (b) student change in mental motivation toward solving problems and critical thinking during an engineering design challenge.

This section provides qualitative and quantitative data. The qualitative section is presented to address a description of the context within which the quantitative data were gathered. While the teaching of engineering to high school students is not a new concept, it has not evolved into a standardized practice. Further, ambiguity surrounding infusing engineering into technology education curriculum takes a variety of forms based on locale and interpretation.

This study draws conclusions based on quantitative data collected from students engaging in engineering design challenges. It is germane to interpreting this quantitative data that the environment surrounding the daily routines, activities and infusion of engineering design specific to this research site is provided.

Quantitative Data

Students were measured at three time points: early October, mid-December and late April with two instruments. One instrument measured achievement developed specifically for this study as described in the methodology section. Mean scores on the different versions of the achievement test were compared. Reliability and ANOVA testing were conducted on the mean achievement instrument scores using SPSS software version 15.0.0. In the methodology section, validity and reliability were discussed in the development of this test.

The other instrument was purchased to measure mental motivation and has been validated and determined reliable for repeated measures designs with high school students. Repeated administrations of the mental motivation instrument were conducted with adequate elapsed time such that one version was administered three times without jeopardizing validity. This is further examined in the discussion, implications and recommendation section.

Longitudinal multilevel modeling was utilized to address research question one and two. Modeling was conducted with R software version 2.7.0 and the linear mixed-effects models package version 0.99875-9 (Bates, Maechler, & Dai, 2008).

Description of Sample

Two sections of students participated in this study by enrolling in two corequisite courses. The total sample size was 53 students on the first of October. Three students failed to complete the fall semester, and an additional nine students dropped the course at the conclusion of the fall semester. Forty-one students were actively participating in the study when data collection was completed in late April. Table 9 shows demographic data summarizing the participant sample. Student enrollment was evenly split between both sections, with dropout rates consistent between sections. Female enrollment in October was 9.50% but increased to 12.20% as a result of male dropout.

Table 9

Study Demographic Data on Participants

	October (Pre)	December (Mid)	April (Post)	Average
Study *n*	53	50	41	48
Section:				
1	28	26	21	25
2	25	24	20	23
Gender:				
Female	5	5	5	5
Male	48	45	36	43
Special education Accommodations	15	15	13	14
Ethic status:[a]				
Majority	32	32	31	32
Minority	11	11	9	10
Unreported	10	7	1	6
Mean cumulative GPA[b]	2.04	2.08	2.16	2.09

[a] based on student self identification.
[b] based on transcript data grades 9 and 10, GPA scale 0-4.

Cumulative GPA had an overall mean of 2.09, on a scale of 0-4. Changes in student enrollment over time increased GPA, which resulted from a disproportionately higher dropout rate of students with low grade point averages. While mean GPA increased, this change was not statistically significant as indicated by Table 10.

Table 11 compared the high school population data to the study demographic data. The percentage of students served by special educational accommodations in this study was 30.00% which is approximately 2.50 times that of the high school. Ethnic diversity data was not reported by all participants. An average of 12.50% did not report. Of the students who did report identifying themselves with an ethnic background, approximately one-quarter of them (24.50%)

Table 10

One-Way ANOVA Summary Table for GPA Change over Time

Tests	SS	*df*	MS	*F*	Sig.
Mean GPA					
Between	0.30	2	0.15	0.21	0.808
Within	99.92	140	0.71		
Total	100.23	142			

Table 11

School Demographic Data Comparing Study and School Percentages

	High School[a]	Study
Special education accommodations	12.60	30.00
Ethnic diversity:		
Majority	78.10	75.50
Minority	21.90	24.50
Limited English proficiency	1.40	NA
Free and reduced lunch	39.00	NA

[a] based on school district publication

were not Anglo American, Caucasians. This proportion is just a few percentage points higher than the school statistic of 21.90%. Data were not collected on limited English proficiency or free and reduced lunch specific to this study; however, the school reported 1.40% and 39.00%, respectively.

Data Considered in Statistical Analysis

Quantitative data were gathered to address the research question. These variables included the following.

Section. This course was offered in two sections. One section was offered in the morning, and the second was offered in the afternoon. Advanced placement courses were, also, offered in the morning which competed for enrollment. Students who chose to enroll in advanced placement courses and this study were excluded from enrollment in the morning section. Knowledge of section of enrollment allowed this factor to be controlled and tested for statistical differences.

Special education status. Nearly one third of the students enrolled were being served by special educational accommodations. By identifying this student population, regression analysis was able to control for and test this disaggregated subgroup.

Gender and ethnic diversity. Statistical analysis has a greater chance of accurately detecting differences that exist between groups if the sample sizes of those groups are substantially large. A field specific definition of minority/majority groups was adopted for this study which collapsed the gender and ethnic divisions into a larger binary variable. This field specific definition aligns with the fields of engineering and technology education wherein Caucasian and Asian males are overrepresented while females and other ethnic groups are underrepresented.

Cumulative GPA. Student transcripts were gathered, and a student's academic success was indicated by a cumulative grade point average during the freshmen and sophomore years. This GPA was based on a 0-4 point scale with weighted courses considered as a fifth point on the scale.

Content area specific GPA. Student transcripts were disaggregated by math, science and communication courses. Individual grade point averages were calculated for each area. The school district identified into which category each course was associated, and GPA's in these categories were computed on the 0-4 point scale.

Achievement test. Student responses were gathered with a 30-item achievement test repeated on three administrations. Development of the test was discussed in the methodology section, and instrument analysis was discussed with findings for research question one.

Mental motivation. The California Measure of Mental Motivation (CM3) identified five subscales. Each subscale was addressed independently for purposes of addressing the research questions and represents a continuous score on a 0-50 scale in this repeated measure. These subscales were mental focus, learning orientation, creative problem solving, cognitive integrity, and scholarly rigor.

Findings for Research Question One

Analysis of Achievement Instrument

Research question number one addressed the students' change in achievement during an engineering design challenge. Data were collected through an achievement test developed for this study. Three versions were administered to the participants on three occasions. On each occasion approximately one third of the class took each test version. Thus, at the completion of data collection, each student had taken each version, but the order in which students took the versions varied at random. Kuder-Richardson 20 (KR-20) formula was used to determine the reliability of the test instruments. KR-20 coefficients ranged from 0.707 to 0.901, lowest in the pretest administration, as shown in

Table 12. Average coefficients for each version ranged from 0.781 to 0.805. Gall and colleagues (1999) indicated that this range of coefficient indicates good reliability.

Figure 1 shows student performance on the achievement tests. Mean scores dropped between October (70% correct) and December (66% correct) but showed gains between December and April (72% correct). Table 13 shows variations between versions

Table 12

Kuder-Richardson 20 Reliability Data for Achievement Tests

	Test version		
Achievement test	A	B	C
October 2007	0.71	0.79	0.71
December 2007	0.90	0.77	0.84
April 2008	0.73	0.80	0.87
Average	0.78	0.79	0.81

Figure 1. Mean achievement scores compared across multiple time points.

Table 13

Descriptive Data for Achievement Tests by Administration

	M (percent correct)	*SD*	*n*
October			
A	70.20	14.00	17
B	70.20	16.00	19
C	70.40	13.90	16
Average[a]	70.20		
December			
A	61.80	23.20	15
B	72.90	15.30	17
C	63.00	19.40	18
Average[a]	66.00		
April			
A	75.70	13.60	14
B	74.60	15.50	11
C	67.50	19.90	16
Average[a]	72.20		

[a] Average is weighted.

for each test administration. Pretest variation was very small, 0.20% between versions. Variation increased in December to 11.10% and dropped a few percentage points to 8.20% in April. ANOVA tests show no statistically significant differences between the versions at each time point (see Table 14).

Hypothesized Model

A two-level longitudinal multilevel model assessed the effects of cumulative grade point average, grade point average in math, science, and communication courses, course section, special education accommodation, minority status, and mental motivation as measured by the CM3 assessment on achievement. It was expected that a potential correlation existed between change indicated by the achievement test and GPA.

Table 14

One-Way ANOVA Summary Table for Test Versions by Administration

Tests	SS	*df*	MS	*F*	Sig.
October					
Between	0.00	2	0.00	0.00	0.999
Within	1.07	49	0.02		
Total	1.07	51			
December					
Between	0.13	2	0.06	1.67	0.199
Within	1.76	47	0.04		
Total	1.89	49			
April					
Between	0.06	2	0.03	1.04	0.364
Within	1.07	38	0.03		
Total	1.13	40			

First-level units were repeated measures within individual study participants. Data from 144 achievement tests were considered for analysis. Second-level units were 53 participants in this study.

In the hypothesized model, individuals and time are declared random effects to assess variability among individuals within time points, as well as variability among time points. Also, one of predictors, mental motivation, was declared a random effect, reflecting the hypothesis that there would be individual differences in the association between mental motivation and achievement.

Longitudinal Multilevel Modeling of Achievement

A main-effects-only model was created and tested against a main effects model that included interactions of time and each predictor. Significance testing was conducted using likelihood ratio tests comparing the model fit using *R*. Significant interactions were included in a model, which was then reduced in a top-down approach. A reduction technique was employed where the least significant predictors were removed one at a time. Each model iteration was compared to the previous model using likelihood ratio test to determine if it was statistically different. The final model was not significantly different than main effects only model, χ^2 (7, N = 123) = -193.466 + 198.118 = 4.6526, $p > 0.05$. Statistically significant predictors in this model are special education status, GPA in previous science courses, and the CM3 subscale of creative problem solving. Special education students tended to underperform their peers. Students who maintained a higher science GPA and also students scoring higher on creative problem solving tended to demonstrate an increase in achievement scores. A student’s status as an underrepresented population member and CM3 subscale cognitive integrity were included in the model but were not statistically significant. No significant interactions were discovered with any predictor and time, which indicates that no significant changes over time were discovered relative to the predictors. Predictor data is shown in Table 15. Note slope estimates were reported as items correct on the 30-question achievement test.

Findings for Research Question Two

Descriptive Data on Mental Motivation

Research question number two addressed the students’ change in mental motivation during an engineering design challenge. Data were collected through an

Table 15

Longitudinal Multilevel Modeling of Achievement Results

Variable	Name	Variance	*SD*	Scale	Estimate	Std. Error	*t* value
Random effects							
STUDY_ID	(Intercept)	12.56	3.54				
Residual		5.79	2.41				
number of obs: 123, groups: STUDY_ID, 43							
Fixed effects							
Intercept					12.57	2.41	5.21
Special education				0,1	-2.90	1.36	-2.13
Underrepresented population				0,1	-2.01	1.26	-1.60
GPA science				0-4	1.24	0.60	2.09
Creative problem solving				0-50	0.14	0.05	2.57
Cognitive integrity				0-50	0.11	0.06	1.93

instrument purchased for this study from Insight Assessment. The CM3 measured five subscales of mental motivation: mental focus, learning orientation, creative problem solving, cognitive integrity, and scholarly rigor. Means for each subscale are presented in Table 16 and, generally, show small growth over time. Scales range from 0-50 and are interpreted by categorization as shown in Table 17.

Hypothesized Model

A two-level longitudinal multilevel model assessed the effects of cumulative grade point average, grade point average in math, science, and communication courses, course section, special education accommodation, and minority status on mental motivation. It was expected that a potential correlation existed between change indicated by the CM3 and GPA.

Table 16

Descriptive Data for CM3 Tests by Administration

	October, *n* = 48		December, *n* = 49		April, *n* = 41	
	M[a]	*SD*	M[a]	*SD*	M[a]	*SD*
Mental focus	27.27	8.09	26.45	7.70	27.54	7.40
Learning orientation	31.90	6.42	31.49	8.46	33.29	7.63
Creative problem solving	29.27	8.20	31.02	8.82	31.39	9.40
Cognitive integrity	33.00	6.61	31.78	7.20	33.44	8.07
Scholarly rigor	26.27	5.73	26.88	6.29	27.76	5.89
Average	29.54		29.52		30.68	

[a] Scale 0-50.

Table 17

Score Interpretation for CM3

Score on CM3 scale	Interpretative category
0-9	Strongly negative
10-19	Somewhat negative
20-30	Ambivalent
31-40	Somewhat disposed
41-50	Strongly disposed

Note: Table adopted from California Measure of Mental Motivation Score Interpretation Document, refer to Appendix Y for full document. (Insight Assessment, 2006)

First-level units were repeated measures within individual study participants. Data from 144 mental motivation tests were considered for analysis. Second-level units were 53 participants in this study.

In the hypothesized models, individuals and time are declared random effects to assess variability among individuals within time points, as well as variability among time points. Mental motivation was modeled for each subscale yielding a total of five models for consideration.

Longitudinal Multilevel Modeling of Mental Motivation

A main effects only model was created and tested against a main effects model that included interactions of time and each predictor. Significance testing was conducted using likelihood ratio tests comparing the models using *R*. Significant interactions were included in a model which was then reduced in a top-down approach. A reduction technique was employed where the least significant predictors were removed one at a time. Each model iteration was compared to the previous model using likelihood ratio test to determine if it was statistically different. This process was employed for each of the five mental motivation subscales.

Mental focus. According to the CM3, a student scoring high in mental focus was diligent, focused, systematic, task-oriented, organized, and clear-headed. Mental focus scores significantly increased over time. A full model was developed which included main effects and significant interactions. A parsimonious fixed slope model was reduced from the full model which was not statistically different, χ^2 (3, N = 123) = 769.84 – 766.74 = 3.1021, $p > 0.05$. Statistically significant main effects in this model were GPA in math, science and time. Students scoring higher in previous math and science courses also tended to be more mentally focused than their peers.

A significant negative interaction was discovered between time and science GPA, as shown in Figure 2. A student's status as an underrepresented population member was

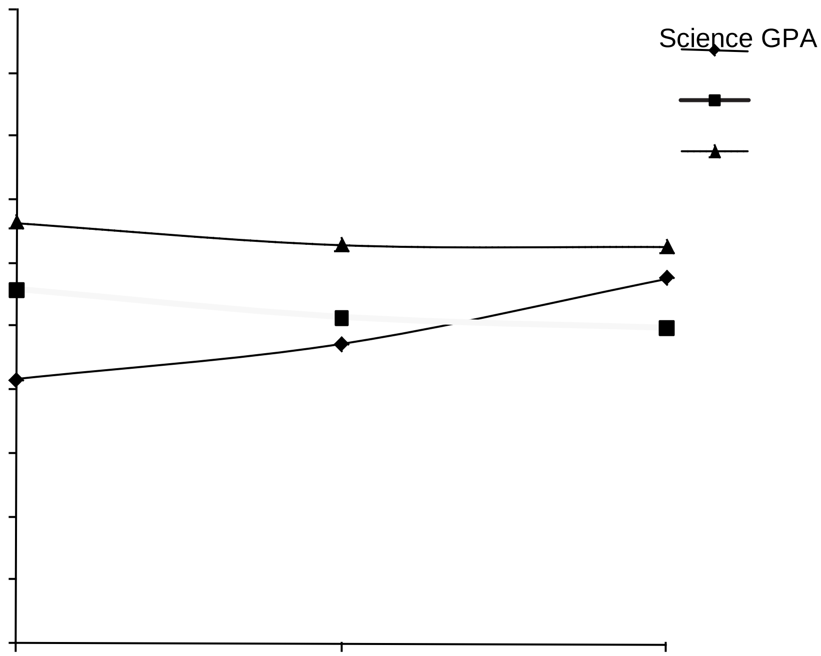

Figure 2. Mental focus scores across time points by science GPA.

included in the model but was not statistically significant. This indicates that knowledge of a student's status as an underrepresented populations increased model fit significantly. However, as a predictor, underrepresented students tended to demonstrate a slightly higher outcome score on mental focus. Predictor data is shown in Table 18. Note that slope estimates are reported in points on a 0-50 scale.

Learning orientation. A student scoring high in learning orientation was motivated by the desire to increase knowledge and skill base as published with the CM3. Learning orientation scores did not significantly change over time. A parsimonious random slope model was reduced from the main effects only model which was not

Table 18

Longitudinal Multilevel Modeling of Mental Focus Results

Variable	Name	Variance	*SD*	Scale	Estimate	Std. Error	*t* value
Random effects							
STUDY_ID	(Intercept)	34.09	5.84				
Residual		16.43	4.05				
number of obs: 123, groups: STUDY_ID, 43							
Fixed effects							
Intercept					14.41	3.02	4.77
Underrepresented population				0,1	1.38	2.08	0.66
GPA math				0-4	2.68	1.29	2.08
Time				1-3	2.48	0.90	2.76
GPA science				0-4	3.55	1.43	2.49
Time*GPA Science					-1.29	0.42	-3.04

statistically different, χ^2 (5, N = 123) = 769.84 – 766.74 = 7.3034, $p > 0.05$. No statistically significant main effects were included in this model. No significant interactions were discovered with any predictor and time, which indicated no significant changes over time were discovered. A student's membership in an underrepresented population is included in the model but was not statistically significant. Predictor data was shown in Table 19. Note that slope estimates are reported in points on a 0-50 scale.

Creative problem solving. According to the CM3, a student scoring high in creative problem solving has a tendency to approach problem solving with innovative or original ideas and solutions. Creative problem solving scores significantly increased over time. A parsimonious random slope model was reduced from the main effects only model which was not statistically different, χ^2 (4, N = 123) = 776.28 – 774.50 = 1.7767, $p >$ 0.05. Statistically significant main effects in this model are science GPA and time.

Table 19

Longitudinal Multilevel Modeling of Learning Orientation Results

Variable	Name	Variance	*SD*	Corr.	Scale	Estimate	Std. Error	*t* value
Random effects								
STUDY_ID	(Intercept)	17.42	4.17					
	Time	5.45	2.33	-.28				
Residual		13.73	3.71					
number of obs: 123, groups: STUDY_ID, 43								
Fixed effects								
Intercept						31.34	.97	32.15
Underrepresented population					0,1	.63	1.74	.37

Students scoring higher in previous science courses tended to score higher than their peers. A student's membership in an underrepresented population was included in the model but was not statistically significant. No significant interactions were discovered with any predictor and time, which indicated no significant changes over time were discovered. Predictor data is shown in Table 20. Note that slope estimates are reported in points on a 0-50 scale.

Cognitive integrity. A student scoring high in cognitive integrity was motivated to use thinking skills in a fair minded fashion, seek the truth, and be open minded. Cognitive integrity scores did not significantly change over time. A parsimonious fixed slope model was reduced from the main effects only model which was not statistically different, χ^2 (6, N = 123) = 786.3 – 777.56 = 8.7385, $p > 0.05$. No statistically significant main effects are included in this model. A student's membership in an underrepresented population was included in the model but was not statistically significant. No significant interactions

Table 20

Longitudinal Multilevel Modeling of Creative Problem Solving Results

Variable	Name	Variance	*SD*	Corr.	Scale	Estimate	Std. Error	*t* value
Random effects								
STUDY_ID	(Intercept)	32.83	5.73					
	Time	2.96	1.72	.34				
Residual		12.19	3.49					
number of obs: 123, groups: STUDY_ID, 43								
Fixed effects								
Intercept						24.51	2.35	10.43
Time					1-3	1.17	.47	2.48
Underrepresented population					0,1	-1.50	2.40	-0.62
GPA science					0-4	2.28	1.07	2.13

were discovered with any predictor and time, which indicated no significant changes over time were discovered. Predictor data was shown in Table 21. Note that slope estimates are reported in points on a 0-50 scale.

Scholarly rigor. A student scoring high in scholarly rigor would tend to work hard to interpret and achieve a deeper understanding of complex or abstract material. Scholarly rigor scores did not significantly change over time. A parsimonious random slope model was reduced from the main effects only model which was not statistically different, χ^2 (5, N = 123) = 713.36 – 709.24 = 4.1195, $p > 0.05$. The statistically significant main effect in this model was GPA in science. Students scoring higher in previous science courses tended to score higher than their peers. A student's association with an underrepresented population is included in the model but is not statistically

Table 21

Longitudinal Multilevel Modeling of Cognitive Integrity Results

Variable	Name	Variance	*SD*	Scale	Estimate	Std. Error	*t* value
Random effects							
STUDY_ID	(Intercept)	33.34	5.77				
Residual		19.11	4.37				
number of obs: 123, groups: STUDY_ID, 43							
Fixed effects							
Intercept					32.39	1.17	27.61
Underrepresented population				0,1	.14	2.08	.07

significant. No significant interactions were discovered with any predictor and time, which indicated no significant changes over time were discovered. Predictor data was shown in Table 22. Note that slope estimates are reported in points on a 0-50 scale.

Quantitative Data Summary

Student achievement was significantly correlated to science GPA, but not math or communication GPA. Achievement score changes over time are not significantly correlated with science, math or communication. Mental motivation was measured by five subscales. Mental focus was correlated with math and science GPA. Mental focus increases over time were negatively correlated with science GPA, meaning that the initial score differential (between higher and lower science GPA students) was decreased over time. Learning orientation and cognitive integrity were not correlated with GPA. Creative problem solving was correlated with science GPA, but gains over time were not

Table 22

Longitudinal Multilevel Modeling of Scholarly Rigor Results

Variable	Name	Variance	*SD*	Corr.	Scale	Estimate	Std. Error	*t* value
Random effects								
STUDY_ID	(Intercept)	28.76	5.36					
	Time	6.04	2.46	-.67				
Residual		7.04	2.65					
number of obs: 123, groups: STUDY_ID, 43								
Fixed effects								
Intercept						23.59	1.37	17.18
Underrepresented population					0,1	.07	1.43	.05
GPA science					0-4	1.82	.64	2.83

correlated with GPA. Scholarly rigor was correlated with science GPA, but change over time was not correlated with GPA.

Knowledge of a student’s status as an underrepresented population in engineering and technology education improved model fit statistically for each outcome considered. While this predictor significantly improved the model, it was not a statistically significant predictor. Chance alone may be responsible for the necessity of this predictor in the model, or a large variance may be masking discovery of an important correlation.

Contextualizing the Research Environment

Researcher bias is an inevitable factor in presenting qualitative data. The researcher in this study was a former high school technology education teacher with five years experience and adhered to high expectations of students. The researcher had a personal interest in engineering and felt that engineering design could be successfully integrated into technology education curriculum.

With this bias presented, the following qualitative data represents a description of what students were encouraged to accomplish during a fall and spring semester at Porter Valley High School. Student quotes, teacher quotes and observations triangulate a common message: Engineering design elements were being applied by the students.

The study was set in a classroom where engineering design was integrated into a technology education curriculum. This integration was taught by two instructors, and this research demonstrates a marriage of technical education focused on fabrication with an understanding of the underlying science and math principles governing the physical world.

For both teachers to understand the purpose of the research, they received professional development focused on six engineering design elements:

1. Problem Definition
2. Solutions
3. Analysis / Modeling
4. Experimentation
5. Decision Making
6. Teamwork

These six elements became main themes of the qualitative data for describing the context of the research site. These themes served to focus data gathering efforts.

Data were collected on the teaching practices which shaped the learning environment in the form of observations, documents, and curricular plans. Qualitative data collected portray evidence that engineering design was a major focus of this course and that students were practicing these elements of engineering design. Additionally, these data serve to demonstrate a model for infusing engineering design into technology education.

The researcher conducted four data gathering visits to the research site, totaling six weeks of classroom observation. Observations began October 1, 2007, and concluded April 25, 2008. Time was split evenly between fall and spring semesters and included a Saturday racing event.

Students who participated in this study enrolled in two corequisite courses. The courses were scheduled together, facilitating the use of a larger block of time as needed. The fall semester and spring semester were formatted differently based on the goals and educational approaches utilized. During the fall term, the courses were distinctly independent, and the instructors acted in relative isolation from each other. One instructor focused on metal fabrication techniques, and the other instructor focused on teaching engineering as applied physics through a hands-on design based format. The concluding projects for each course in the fall term set the stage for design and fabrication of the engineering design challenge that officially began with the spring term. The spring term was initiated by assembling teams and focusing on defining the problem. The lab environment was a common area shared by both instructors. While students were in the lab, the instructors worked interchangeably with teams assisting with design and fabrication. Instructors consulted with each other when in doubt, but, generally, both were comfortable with all aspects of the design and fabrication. Though typically both instructors were present, one was either on his planning period or responsible for another group of students (unrelated to the study) who were sharing the lab.

Fall Semester

Six main units of instruction were used in teaching engineering design during the fall term. These six units included magnetic levitation, electric motors, solar power, gearing, and two scale modeling experiences. These units were examined during the teacher professional development in order to identify opportunities to integrate each of the six elements of engineering design identified for this study. Agreement was reached with the teachers as to how and when these six elements would be included during the fall term. Data were gathered to demonstrate the teacher and student interaction with these six elements. Examples of students' work are presented in combination with classroom observations.

Problem Definition

Throughout the fall term, students were presented a variety of challenges. The responsibility for defining the problem transitioned from a heavily teacher defined problem to a student defined problem as the semester progressed. A review of student journals revealed students were focusing on identifying the problem. An excerpt from Jerome's journal highlighted his reflection, "Our project was to design and construct [a] maglev car with a propeller propulsion that will be balanced [and] stable. And race the full length of a 16 foot track in the shortest amount of time." Cori illustrated her thoughts as she went beyond the surface level problem to recognize aerodynamics are a key subcomponent of the actual problem at hand, “The first thoughts I had on doing this project were on how I was going to be able to make my car aerodynamic. I figured I would have to carve out the body to….” Students identified constraints as part of their problem definition. Near the end of the fall semester, students were assigned the design problem of creating a 1/10 scale model as a prototype for their electric car. One constraint they faced was an ergonomic accommodation of the driver. In Cori’s words:

> Starting this project, it seemed like a lot of work, in order to make the miniature car work. So to start it off we began by taking all of our needed measurements of our driver. This would allow us to build the frame and body of the car around that of our driver’s body.

Cori’s comments described Figure 3, which shows data gathered by a student team on their driver’s dimensions. This constraining factor was of constant consideration as it interacted with aerodynamics and physical size restrictions for the cars. In another project, constraints were laid out in the design brief presented to the students by the instructor in bullet point style.

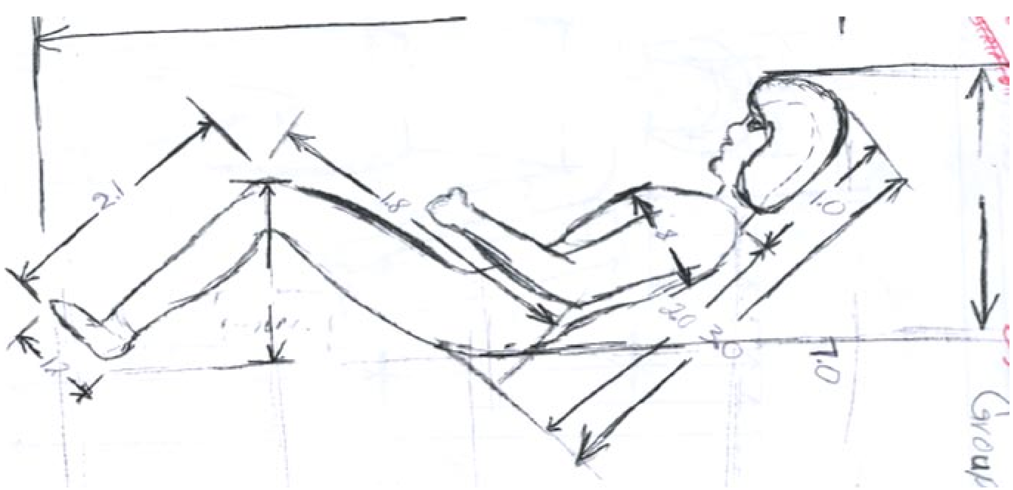

Figure 3. One-tenth scale driver sketch with dimensions.

Evidence of evaluation criteria was produced by the instructors and the students. During a few projects, students were presented with a rubric sheet that included 5-10 areas on which their project would be evaluated. This was a teacher generated form presented with the project briefing. Johan stated in his journal, “We tested the 5 minute run time. Our motor exceed the 5 minutes and ran for 15 minutes plus.” In this instance, the student group had set a more stringent goal than had the instructor, but evaluation criteria followed the same testing procedures. Johan followed up with, “We were really proud!” Additionally, students evaluated their peers and each other using a teacher generated rubric, further discussed under the teamwork heading.

Solutions

Students were expected to develop solutions to their challenges, these solutions evolved from research of existing solutions and brainstorming alternative solutions. As written by Johan, “When we started our project, we look at the examples and tried to see how we could perfect it. We decided to make.…” The instructors provided examples of previous student work and often presented a critique of a few examples during lecture. Students were encouraged to brainstorm and expected to document with sketches the various ideas developed. Evidence of the brainstorming sessions was a required component of student journals and assembled into a final report which accompanied the project for a grade. Students were expected to report details describing their solutions. Cori commented:

> I figured I would have to carve out the body to make a chamber for the air to go through so the propeller would have more wind hitting it. The next thing I thought about was how to raise the motor up. I decided to use slightly thicker pieces of

> foam so that they were more stable and have the edged rounded so that it would add to the aerodynamics of my car.

Analysis/Modeling

Students conducted analysis in a variety of activities. Students learned about gear ratios and practiced calculations of motor rotations per minute and wheel rotations per minute given a certain gear ratio. They were expected to be able to calculate gear ratios based on a given sprocket's number of teeth and a pulley's diameter. They also worked through calculations to determine the velocity of a car, given a gear ratio, motor RPM and wheel diameter. Students began to articulate connections between variables governing velocity of their moving projects. Johan stated: "In all, I found that the less friction and less wind resistance, the better your car will go down the track, and the faster it will move." This realization that specific variables govern the physical behavior of our world was a key component of this course according to the instructors.

Students made calculations of power based on the voltage and amperage generated by a pair of solar panels. They practiced calculating power to discover the power produced by a series circuit, and a parallel circuit should be the same while the voltage and amperage vary inversely. Students also gathered data on solar power wattage based on distance to a light source. Students took six measurements, calculated power and created a data table. An example of Chinelo's data is shown in Table 23.

In this example, he made a few multiplication errors in calculating wattage; however, the plot of distance and power (refer to Figure 4) appropriately resembles an exponential curve. Using this data analysis, students were asked to estimate the power at

Table 23

Example of Chinelo's Solar Power Data Based on Distant to Light Source

Distance (inches)	Voltage (volts)	Current (amps)	Power (watts)
0	2.35	.55	1.245
3	2.82	.31	0.626
6	1.94	.265	0.680
9	1.85	.24	0.444
12	1.81	.24	0.316
24	1.74	.06	0.123

Note. Data gathered from student worksheet.

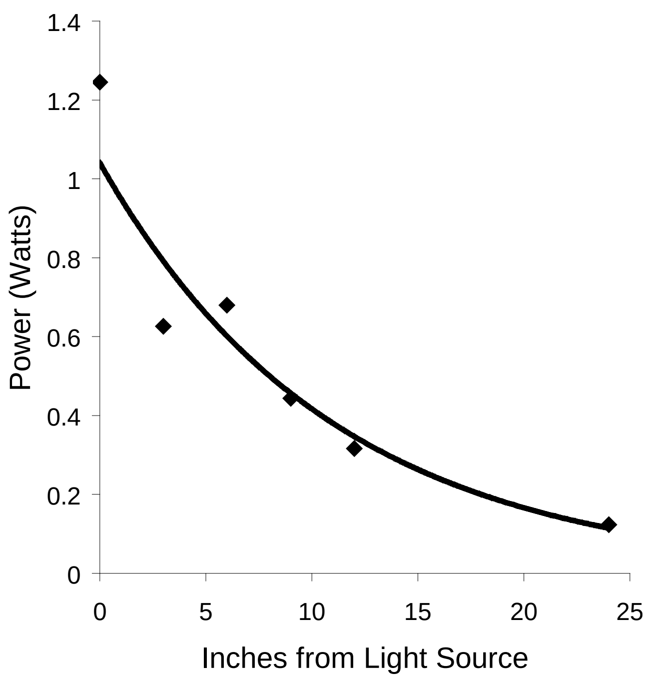

Figure 4. Digital representation of student hand drawn plot.

a distance they had not measured. Chinelo predicted, based on his curve, the power at 20 inches from the source would be approximately 0.159 watts.

As a component of learning analysis, students encountered inconsistencies in data collection. Students attempted to deal with uncertainty in measurement and performance by taking multiple measurements and calculating averages. The researcher observed teams talking about outliers (though not using this term) when referring to measurements that were dramatically higher or lower than other data collected. Typically, students noticed outliers when they inadvertently started a timer too early or late in comparison to other trials. They used the average speed or times in their calculations. This allowed teams to compare their data to other groups with more confidence that their measurements (and calculations based on these measurements) represented reality.

Experimentation

Each unit of instruction had some element of experimentation. Students gathered data and prototyped a solution to each challenge. In Cori's words, "Today we listened to [Mr. Brewer] explain how to use the multi-meter. Then, we went and started finding the volts, amps, and watts that the four different solar panels had." This journal excerpt reflects on gathering data on power based on the distance the solar panel was to the light source. In a following activity, students created a winch powered by the solar panels and lifted small weights. By measuring the amount of weight and time to lift a set height, students could compute a horsepower calculation based on a series or parallel circuit. Cori explained:

Today [Mr. Brewer] explained more on how to setup the gearing to test which

> type of circuit is better in providing more horsepower. Then Asmara and I got to test our system. We also took and did 3 trials of each of the three types of circuits to get a more accurate timing.

In determining horsepower, students made multiple trials, varying the amount of weight being lifted. The resulting horsepower increased to a peak, then dropped as the motor became overloaded. These various horsepower calculations were not graphically plotted by the students, but a trend was discovered that would have looked like a parabola, where a peak power can be discovered based on an optimal balance of torque and speed. Students added or removed weights and recalculated horsepower to optimize their output. Information gathered from these calculations informed student choices on a solar powered car design. This data provide a starting point for experimentation using the same motor and optimal circuit wiring (series, parallel, series-parallel).

Following the theme of power calculation, students designed and fabricated an electric motor (refer to Figure 5). In this challenge, students refined their design based on

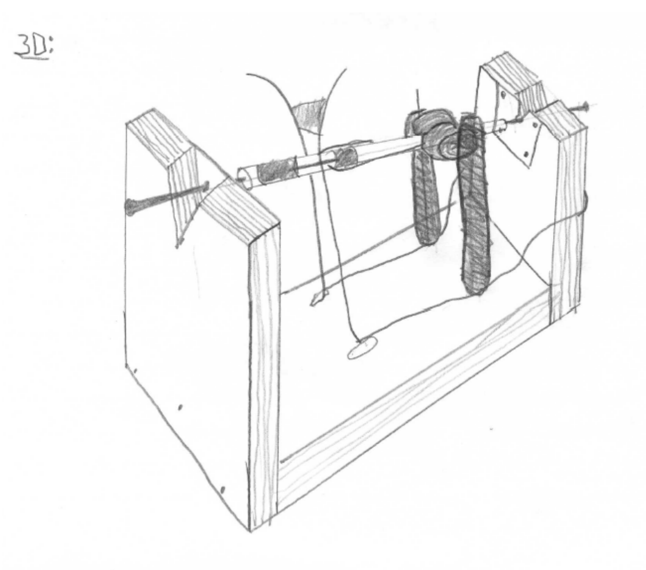

Figure 5. Student sketch of electric motor design.

data gathered on horsepower. A string was wrapped around the armature and used as a winch to lift weight. Using the same technique as the solar power calculations, students analyzed the horsepower output of their motor made changes to increase performance. Jovan commented of the iterative process,

> My second problem was, I couldn't get my brushes to work. This problem came with baggage. My coils weren't wired the right way and then I had to make my brushes to where they wouldn't short but also have contact for as long as possible. I fixed it by kinking my brush to a point and having it lightly touch the commutators.

Jovan articulated in his report that the experimentation he was conducting tied to an understanding that the magnetic fields caused motion (and power) in the motor. The longer the brushes contacted the commutators, the more powerful his motor. He recognized a tradeoff in the increased contact time with the commutators and the increased potential of a short circuit (if overlap occurred).

Decision Making

Students were presented with opportunities to make many decisions throughout the fall semester. Observational evidence suggested that students used sketching and conversation to discuss alternative solutions. When students were working in teams, they discussed ideas and often, concurrently, attached valve judgments. While students were encouraged to separate brainstorming from decision making, regularly students engaged in the two activities, simultaneously. In addition, students reflected on their decisions when asked how it could be improved. Cori stated in a reflection of the 1/10 scale model:

> Some of the ideas I have to make our full size car better, that were not considered while making the 1/10 scale car is to have the foot pedal instead of a thumb throttle. Some advantages to a foot throttle are in having a more familiar feel in

> the driving of the car. The second reason that this would be preferable is that there are frequently problems with the thumb throttles jamming or breaking during a race, taking lots of valuate time to fix. One disadvantage of this however is that it would limit the height of the people that we could have drive our car.

In this excerpt from her final report, one decision is considered with advantages and disadvantages. Students documented decisions they made in a similar fashion highlighting choices and identifying positive and negative attributes in order to make an informed decision. Dante reflected on decisions he made on a magnetic levitation car, "I learned here that making it look cool doesn't make it move[,] so for the Electrathon vehicle in the spring, I will make it simple but with all the necessary components made right for functionality."

Quantitative data were also used to drive decision making. Students used calculations of horsepower to assess changes in their electric motor designs and determine how to wire the solar panels. In brainstorming and preparing a design for the 1/10 scale model car, students gathered quantitative data on driver size (discussed earlier). These data served to constrain decisions on how the driver would comfortably fit into the car when designing the 1/10 scale model. Jovan provided evidence that he used quantitative information presented in lecture to drive decision making process during the design of the electric motor. Jovan noted a relationship between magnetic strength and distance in his electric motor design, "I want to have my armature to clear my field magnets barely. [Mr. Brewer] said if it's twice the distance it only retains 1/4 of the magntivity [magnet strength]."

Teamwork

Teamwork was a critical aspect of this course. Students started the semester with a project in which they worked as individuals, but as the semester progressed, nearly all activities required students to participate in teams. This progression from individual to small groups (then larger groups) allowed students to practice their communication and leadership skills. Students were presented with information on team dynamics such as how to select team members, leadership and group responsibilities. One of the student handouts suggested students considered team members carefully, “As with all team selections you may want to have a member with different skills than you so that they can help complete various tasks.” The team leader, “…should be able to delegate tasks well, not try to do it by themselves.” As the semester progressed, team members gained autonomy in their work habits. Early in the semester, each team member was involved with nearly all aspects of the project, but as the semester progressed, team member autonomy was practiced. Students were expected to discuss plans and divide responsibilities to complete the jobs as suggested in a handout, “The team leader will compile a list of the members of the team and each person will chose one or more tasks on the car that they will be in charge of.”

Communication was an important element of teamwork and was used in various forms. Students had formal team meetings where a leader facilitated progress, recorder compiled notes on brainstorming, plans and delegation of responsibilities. Cori, her team’s leader, documented, “I was the one who measured out and did configurations on the foam. Asmara would then cut out the pieces that I measured and Cédrick would do a fantastic job of sanding them down." Student sketches were a required part of the journaling and reporting process. In Figure 6, Jenson, Joseph, and Jace finalized their sketch for the 1/10 scale model car. This form of visual communication was commonplace among the students as was verbal communication in team meetings.

Fall Emergent Themes

Two strong emergent themes developed throughout the fall semester and were interwoven into each learning experience. One was the intense focus on preparation for

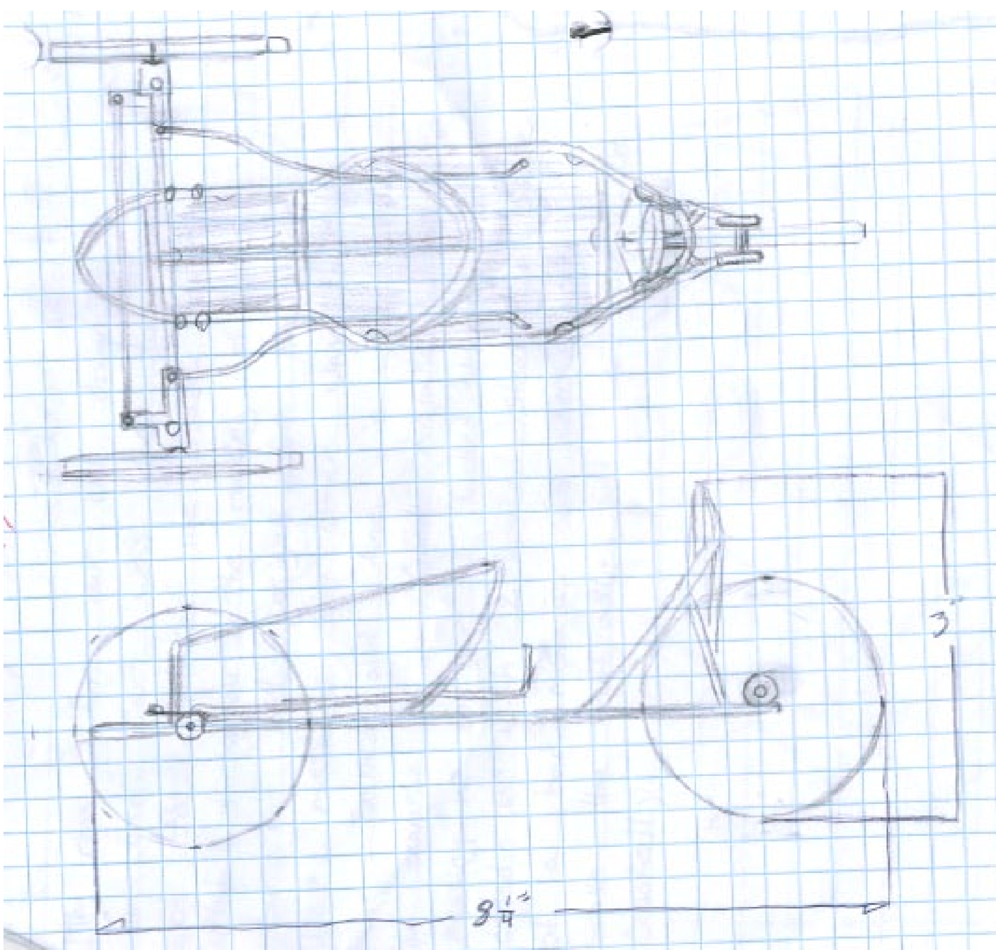

Figure 6. Sketching as a form of team communication.

the large spring design challenge. The other emergent theme was a transition from well-defined problems to ill-defined and was increasingly open-ended as the semester progressed.

The focus in the fall on preparation for the spring challenge was discussed with the students and observed by the researcher. Each activity in the fall connected to some aspect of designing, fabricating, and learning to work as a team. Students learned to weld and practiced cutting, bending, and mechanically fastening metal in methods that could be used in layout and construction of the electric car. Students practiced on the same metal thickness and welding positions that would be directly transferable to the spring challenge.

Aerodynamics of the magnetic levitation car directly transferred to their electric car body with an intermediate step learning about fiberglass plug-mold technologies through their 1/10 scale model car design. Analysis of gear ratios and calculating speed based on motor rpm during their solar car activity transferred to the larger wheels in their spring challenge. The realization that theoretically gearing the car to go faster may actually make the car go slower (as the motor stalls) was a real experience in optimizing the gear ratio of the solar car and winch.

Team size gradually increased in preparation for teams of up to six students in the spring. Thus, practice in leadership and participation were practiced before the spring challenge. While the rules for the spring challenge were well-defined, they focused primarily on safety and fair competition. Car design was largely an open-ended and ill-defined problem. As the fall semester progressed, students experienced an increase in their responsibility to determine the problem definition and evaluation criteria.

One of the capstone fall projects included a 1/10 scale model car, designed, and fabricated from steel frame members. Teams made fully articulated scale driver models to ensure the frame design fit their driver. Wheels and steering linkage were functional. Moving the steering wheel (or levers, as the case may be) moved 1/10 scale tie-rods which moved steering wheels. Mockup batteries and motors were in place to demonstrate fit and consideration of weight and balance issues.

The other capstone fall project was a miniature frame welded from full size material. This frame project was fixtured on a small section of plywood and laid out just as the full size car would be a few weeks later. Students discovered the challenges associated with cutting and fabricating steel tube and flat stock at predetermined angles. The instructor provided some of the dimensions as constraints and allowed students to design other aspects of the frame. The required dimensions forced student teams to figure out how to measure and fixture their material to match specifications. This learning experience transferred to the full size car project as their design specifications were laid on a larger plywood board, and angles were critical for steering and frame squareness.

Early projects in the semester were clearly defined and had focused evaluation criteria determined by the instructors. Design briefs listed evaluation criteria for the students to follow. The magnetic levitation design brief stated, “Design and construct a maglev car with a propeller propulsion that will be balanced, stable, and race the full length of a 16 foot track in the shortest amount of time.” Students were provided with a list of constraints and materials available. In another early activity, students designed an electric motor. Their design had some freedom, but a 19-step assembly method narrowed the list of potential solutions. Each motor looked different and, in particular, students' designs for the brushes varied. However, in later assignments, a much greater degree of freedom was promoted, thereby, expanding the problem and solution space with ill-defined problems.

As the capstone fall project, the 1/10 scale model provided students with many opportunities to address creatively the problem. The design was required to be scaled and, potentially, a car the team might want to build in the spring. Decisions on steering, weight distribution, driver position, frame and roll bar design were entirely up to the students. This ill-defined problem yielded many unique and differing solutions. Students' problem definitions varied from rider comfort as a priority to aerodynamics as a higher priority, evident in the rider position from recumbent to upright. Ergonomics and aerodynamics are examples of design considerations (at times conflicting), but additional considerations such as safety, impact resistance, durability, and weight were in students' dialogs.

Spring Semester

The spring semester marked a dramatic change in educational pedagogy. Students focused on one large design project, rather than multiple small ones. The two-period block was supervised by one instructor during the first half and the other instructor during the second half. The instructors were observed discussing what they would present to the students in order to blend appropriately reinforcement of important concepts without repeating instruction. Students had one goal: to design and build an electric car for the weekend races. A sense of competition was felt as participation in each weekend race lead to an increased state standing. The state standing score for each car was a composite score for the season to date. Students actively participated in as many races as possible to increase their team's standing. Excitement surrounded the competition which carried over to the classroom and motivated student teams.

Problem Definition

In defining the problem, teams were encouraged to ask questions of the instructors, peers, and students who had previously taken the course. Teams defined for whom the vehicle was designed and what purpose the vehicle would serve. Students informally identified issues of ergonomics, weight and balance, driver view of other cars, maneuverability in tight corners, and aerodynamics.

Constraints were imposed on the project which included the Electrathon competition rules (Electrathon America, 2007). While non-negotiable, these rules governed only two aspects of the design: safety and fair competition. Teams had a limited supply of materials and a seventy-five dollar budget for consumables not provided by the teachers for the challenge. Funds were raised by some ambitious teams, but these teams were constrained to work during personal time (extracurricular). Teams were constrained by a limited timeline of two periods per day. While the lab was open informally after school hours, the expectation was that students could solve the problem in the allotted time. Team designs and fabrication had to be considered a safe and appropriate use of tools and materials by the instructors. Additionally, cars were constrained to a physical size limit for facilitating storage and transportation to the competitions. Students further defined their own constraints, such as: all members of the team could fit in the car, rather than just the team's designated driver.

Student designs were evaluated on multiple levels. Evaluation was done by the instructors as to how well the design conformed to Electrathon safety guidelines. Students made informal evaluations of designs during the brainstorming sessions. The extent to which the prototype car followed the design was consistently and informally evaluated by students. Jerome commented, "Today we made a crappy roll bar that wasn't symmetrical! We ended up starting a new one."

Solutions

Opportunities to research existing solutions were provided. Exemplar cars representing previous successes and failures were stored in the lab for student inspection. Students spent time driving various cars from previous years and informally evaluating the overall feel of the car, and assessing individual aspects (i.e., steering, drive train, ergonomics, etc.).

Students were encouraged to conduct a miniature "literature review," wherein, they searched the internet, books, magazines, pictures, and other sources. Students photographed, videotaped, and interviewed teams from other schools during competitions. A sense of information sharing was evident at the race attended by the researcher. Students were not only sharing current plans, but ideas for future designs and tools.

Students were required to document evidence of brainstorming. Participants conducted formal and informal brainstorming in individual and group settings. Many sketches and ideas were described in daily journaling and team reports. One example of sketching potential car designs is displayed in Figure 7.

For the car design, activities in the fall served as brainstorming evidence in the form of 1/10 scale models of the frame and body. These models included functional steering linkage, an articulated model driver, wheels, battery, motor, and wiring

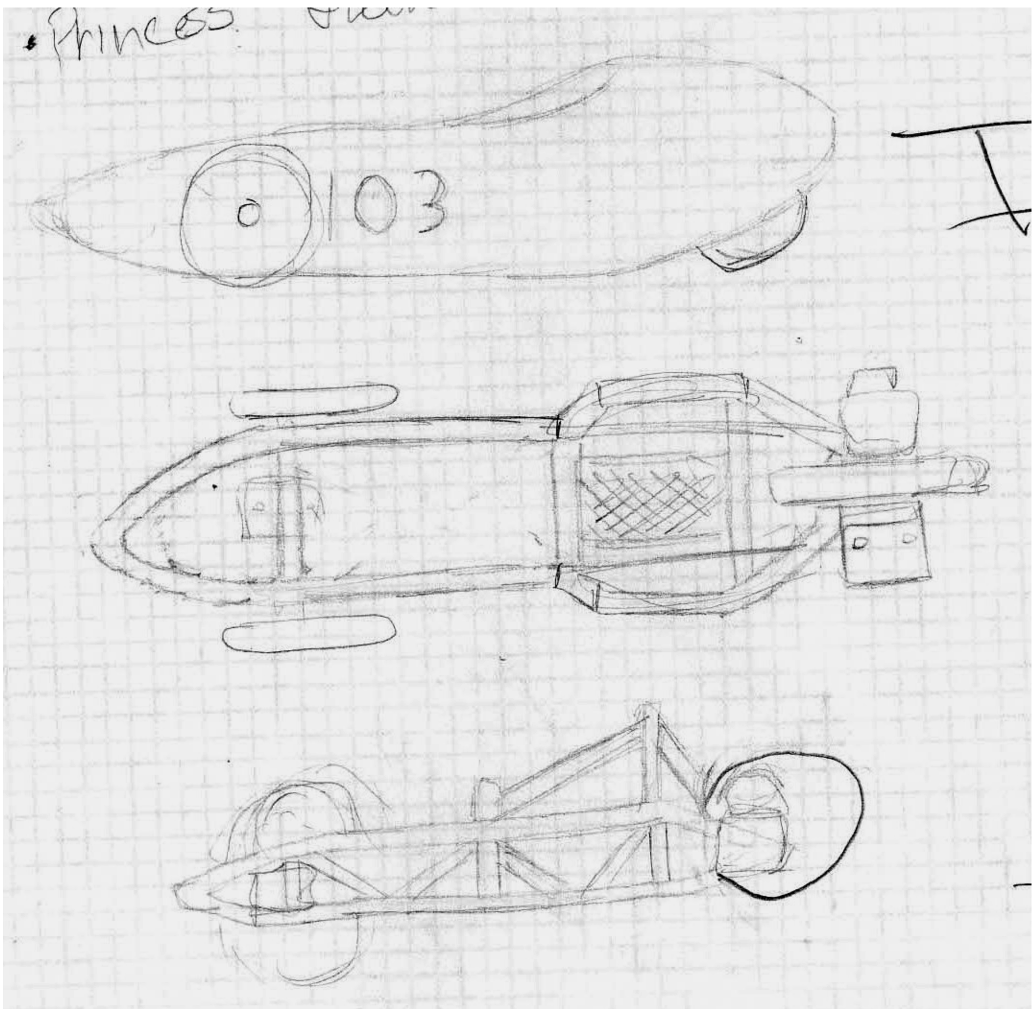

Figure 7. Keila's brainstorming sketch.

mockups. A mini-frame project using a jig provided rich experiences upon which to flavor the spring brainstorming activities. Students had a realistic impression of the challenges involved with alignment, welding, and metal fabrication from their capstone fall term projects. Students were encouraged to consider multiple solutions and not fixate on their first idea. The 6-3-5 brainstorming method of team idea generation was used by teams. In this process, each team member generated three ideas. The ideas were described or sketched on a piece of paper and passed to the other team members. Each team member was expected to provide written comment or annotation to the ideas. The name "6-3-5" is, thus, derived from a six student team, generating three ideas each and passing their paper to the other five students for comment. Collen's ideas included the following:

> I think we should use a drop axle so that it is easy to assemble, plus it would fit the [driver's] body. The hand steering would be best for more room in the center. No suspension due to addition height from little parts. For the body, we should have a fiberglass nosecone with an aluminum body. A canopy roll bar would be good.

Peer commented included, "I agree with everything," "Sounds good," "Yep," "I agree because it would make the car better." Typically, student comments focused on agreement, "Yes, allows more aerodynamics." "I think it [would] be better to have a 2 handle steering because it would be easier for the driver to drive."

Analysis/Modeling

Analysis and modeling was facilitated on multiple levels. In the professional development, agreement was reached that students would be presented with the concept of energy modeling. It should be noted that the researcher did not directly observe a formal presentation of the energy model. However, the instructors were observed lecturing on components of the energy model and its relationships to car performance and, therefore, it is presented here as agreed upon.

As discussed in the professional development, the energy model provides focus for students as they attempt to refine their design and optimize car performance. On a conceptual level, energy conversions were modeled in terms of "losses." Chemical energy in the battery was converted to electrical energy. A portion of the energy is utilized in creating forward motion of the vehicle. However, energy was "lost" in terms of friction which is resisting the goal of forward motion. In this model, the focus was reducing energy "loss" by minimizing rolling resistance, drive train friction and wind resistance. These three variables were discussed as functions of aspects of the design process that students were capable of manipulating. Rolling resistance was discussed as a function of Ackerman steering, toe in/out, axle tightness, tire pressure, wheel bearing friction, and brake drag. Drive train friction was a function of chain tension, sprocket alignment, and motor bearing friction. Wind resistance was modeled as a function of aerodynamic drag. It was recognized that this model is limited, but it was, purposefully, created to maintain a developmentally appropriate means of analysis for high school junior students.

Quantitative analysis of rolling resistance was conducted by measuring battery voltage and amperage draw of the motor. While driving the cars, students paid attention to their speed, measured by a bicycle computer and amperage draw (measured by a shunt). This data provided feedback to drivers in order to maximize battery life and distance traveled. Students used this data to drive decisions on gear ratios. Most students could explain their gear ratio, why they chose this ratio and identify their predicted speed.

Ackerman steering was analyzed using paper on the floor. While the car drove slowly over the paper, any sliding of the paper indicated improper turning radius on that wheel. Wheels were spun by hand and timed to measure bearing and axle friction. Drive train friction was measured by lifting the drive wheel and measuring amp draw of the motor. Wind resistance was modeled using the 1/10 scale cars with bodies created in a wind tunnel by measuring drag force with a scale. Students dealt with uncertainty by taking multiple measurements and averaging the values. Additionally, students were asked why outliers may be present in their data. Students made estimates during a variety of occasions, including setting angles for steering (camber, caster, rake), material size and weight tradeoffs regarding construction choices and costs of materials in their designs.

Students recognized variables pertinent to the success of their design such as aerodynamics, overall weight, and stability. Chandler states, “I think it [the car] should have a drop axle so that we can keep the battery and motor below the axle so I don’t flip.” Chandler was referring to the center of gravity and its impact on stability and used this insight to drive his team’s design.

Experimentation

Students conducted experiments based on analysis by conducting the rolling resistance, drive train and aerodynamic measurements. During the experimentation, students made changes they thought would increase performance, and retest. This iterative process helped students reduce the infinite number of variables which may increase performance to a more manageable set of choices. During lectures, the instructors reminded students that rolling resistance, drive train friction, and aerodynamics are key variables to be addressed. Students experimented with balance and weight distribution and its effect on handling. Students gathered empirical evidence during their testing and experimentation as described earlier under analysis.

The students prototyped during the fall with their 1/10 scale model car and body represented an iteration of the car in the design process. The mini-frame prototype featured a layout method new to most students that would assist in fabricating a straight frame with bilateral symmetry.

Teams used each race as an experiment in driver technique and car performance. Students discussed what changes they might make to increase performance of their car as measured by race results and amperage draw while driving. Changes were made each week in preparation for the weekend race. The racing season started in March and continued into the summer. This schedule facilitated an iterative process of design and redesign with weekly testing. Students were engaged eagerly in reflection and preparation for each weekend.

Decision Making

Students made decisions in a variety of ways including the use of a decision matrix. Students were coached, initially, with alterative designs and criteria. As the students became familiar with the decision making tools, gradually, they began to develop their own criteria and supply creative alternate solutions for evaluation. Examples of optimizing the design included determining tire pressure, electrical resistance, and gearing, as a few examples. Design teams drove their cars with various tire pressures and discovered that, while a higher pressure reduced rolling resistance, it decreased cornering abilities. This tradeoff was managed by teams through experiential manipulation of the pressure while attentively driving the car.

Electrical resistance was measured using an ohm meter. Reducing electrical cable length, increasing cable thickness and increasing connection surface area reduced resistance, but may lead to poor weight distribution or increased weight. This tradeoff was balanced and managed by the students as a design consideration.

Race tracks varied in length, elevation gain, and cornering and, thus, speeds required to win each race varied. Students optimized gear ratios for their cars based on calculations for speeds and posted results for previous years' races.

While the 6-3-5 brainstorming method was intended to generate alternatives, it doubled as an opportunity to make decisions. Team member comments led to developing a list of characteristics for each team's design. One team lists, "Drop axle, rack and pinion, thumb throttle, 20" tires, disc brakes, driver lying down, weather stripping, hand brakes, 5 point harness seat belt." These characteristics were developed in a team meeting and provided focus for the efforts of multiple team members often working independently.

Teamwork

Development of teamwork skills began in the fall and continued with increasing intensity during the spring. Effective communication was a heavily emphasized component of teamwork. Teams were allocated time at the beginning and end of each period for planning, documentation and decision making. Teams kept records of plans and ideas in a team journal.

To encourage individual participation in the team activities, instructors also evaluated student efforts in the form of skill grades, journaling, reports, time accountability sheets and job/task analysis. Students participated in the evaluation process through self and peer evaluation (refer to Table 24) and while journaling. Time sheets hold each member of the team accountable for making progress on the project. On each sheet, students documented what work was accomplished, how long it took, tools used, and total time on task for the day.

Team leaders assisted the team in identifying tasks and who would be responsible for completing them. Jerome journals:

> In our team group we decided that Andre would make our C-brackets and drill them and Brayden would make the back plates and Jerome would make the stand for the back axle. Our problem of the day was Andre quenched our C-brackets.

The journals also provided a daily log of work accomplished. Presented here is an example of the daily log:

- Plan to get sides of frame done. Cut and tack welded into place.
- Got all sides cut and most tack welded, trouble with two of the angles not matching up.

Table 24

Reflection on Team Member Performance During a Bi-Monthly Assessment

Name of lab partner	Grade	Explain grade and contribution
Ted	A	Good worker always
Cori	A	Good leader, works well with others
Collen	B-	Doesn’t really actively look for something to do. But works well when given a job.
Joseph	A	Works well with group. Finishes what he starts.
Cédrick	C	Isn’t always here, helps but isn’t very active

- Get a start on the nose cone, finish first battery cage and start second, weld sides
- Got start on nose cone, angles cut wrong so battery cage not done and sides are welded.
- Plan to cut roll bar to length, angle [illegible] and weld it on, also get connection arms welded on.
- <u>Big problems</u> with bar but got the connection arms tacked into place after cut to the right angle.
- Finish welding connection arms, make tie rod and get roll bar on
- Made tie rod and welded the connection arms but still don't have the roll bar on.

Students began and ended each period with a team meeting. Journals were, typically, used at the conclusion of the period to document progress and, in some cases generate goals for next period.

Spring Emergent Themes

Two themes emerged which contributed to the success of the learning environment during the spring. One of these was that team members worked simultaneously on different aspects of the project. The second theme was that the instructors balanced an open-ended problem with some constraints.

The spring design challenge was a large scale project requiring all team members to participate. Design officially began in January, and the race season started two month later in early March. In order to design and build a car, team members were forced to work in parallel, individually developing aspects of the car that would fit together as a larger system. In part, this was successful because teams communicated during their meetings and agreed upon their plans.

Team designs varied from team to team, but each group used some standard components. Constraining a few of the design aspects reduced an infinite solution set to a more manageable level. All teams were issued identical twenty inch wheels and a motor. Therefore, designs held this constraint as a constant allowing creativity and individuality to develop regarding how and where to mount the wheels. The brackets for hinging the axles on the kingpins were similar across each team. This provided students the opportunity to learn to use specific shop equipment in the fall for producing the parts. The theme of standardizing (constraining) a few elements of the car facilitated fabrication of those elements in isolation of other interconnected components. The ability to create components (or sub-systems) that fit together during assembly was a key element in ensuring each student's could actively participating in design and construction.

Qualitative Data Summary

Qualitative data were gathered through teacher observation, student observation and documents. The purpose of this data was to provide a description of the context to: (a) demonstrate engineering design elements were present during this study, (b) provide an example approach to be replicated or adapted, and (c) extend generalizability by highlighting teaching pedagogy and student response. To these ends, data were not gathered on all students, nor were all students equally represented. Rather, data were gathered to provide evidence of the teaching and learning environment which showed students participating.

CHAPTER V

DISCUSSION, IMPLICATIONS, AND RECOMMENDATIONS

Kindergarten through twelfth grade education has been identified to facilitate fostering a technologically literate society (Gamire & Pearson, 2006; Gorham, 2002; ITEA, 1996, 2000; Pearson & Young, 2002). To be technologically literate includes developing an understanding of the engineering design process (ITEA, 2000). Engineering design challenges are a way to bridge the divide between technology education and engineering as they provide an opportunity to focus efforts on a design project while applying engineering principles.

Previous quasi-experimental research (Cantrell et al., 2006; Dally & Zhang, 1993; Dunlap, 2005; Dym et al., 2005; Griffith, 2005; Irwin, 2005; Lentz & Boe, 2004; Marra et al., 2000; Ricks, 2006; Romero et al., 2006; Roselli & Brophy, 2006; Weir, 2004; Yaeger, 2002) has established that engineering design challenges are successful in increasing student achievement and attitude toward learning. However, limited and conflicting evidence suggests the academic background of a student may impact their experience during the engineering design challenge. Cantrell and colleagues concluded engineering modules reduced achievement gaps of most ethnic minority groups. Weir also differentiated her data based on student groups, but she considered an academic top half and an academic lower half in a university engineering course. Her conclusion was that the upper half improved significantly ($p < 0.05$), while the lower half was not significantly ($p > 0.10$) different between the pre and posttest measures.

Discussion

Achievement

In this research, student achievement was significantly correlated to science GPA, but not significantly to math or communication GPA. Therefore, a student participating in this study was likely to perform better on the achievement test if their science GPA was higher. The differences are not only statistically significant, but they are practically significant. To quantify the practical significance, consider an example: the mean scores in October were approximately 70% correct, and the average science GPA was nearly 2.00. A typical student who failed previous science courses would tend to score 10% less, or about 60% in this example. Conversely, a student who earned a 4.0 GPA in science would tend to score about 10% higher, or about 80%. Knowledge of previous performance in science lends substantial prediction capabilities to a student's performance in this achievement test.

Previous performance in math and communications courses did not provide significant prediction capabilities in the modeling. This indicated that students who performed poorly in math or communications were not disadvantaged significantly over their higher GPA peers. Though math and communications GPAs were not statistically significant predictors, a positively correlated trend was noted. Students with a higher math or communication GPA tended to perform better on the achievement test. Special education status provided significant prediction in the model. Special education students tended to score about 10% less than their regular education peers. While this number is statistically significant, the practical difference was questionable. Special education study participants represented nearly one third of the study sample. This proportion was approximately 2.5 times greater than the high school demographic. Generally speaking, special education students received additional educational services to be successful in school. However, in this study, they performed only about 10% under their peers without support on the test.

Achievement score changes over time were not significantly correlated with science, math or communication GPA. This indicated that slope modeling for higher and lower GPA students does not show statistically significant changes over time. Therefore, higher GPA students were not advantaged or disadvantaged over time in comparison to their lower GPA peers. This interpretation needs to be considered conservatively as class mean scores did not change significantly over time. The lack of significant mean change over time potentially indicated students did not learn (in a measurable sense) during this course. Alternatively, the achievement instrument may not have fully captured the essence of learning which did occur but was not measured. While speculation regarding why students did not show improvement over the seven month study was non-conclusive, the scores for lower GPA students did not drop significantly. This does indicated that lower GPA students remained active in their participation in course experiences which included the achievement test. Cantrell and colleagues (2006) and Irwin (2005) measured high school student achievement growth, and both indicated improvement, while only Irwin indicated significant improvement.

Student status as a member of an underrepresented population group improved the model fit statistically, but was not a statistically significant predictor. The mean difference between majority and underrepresented populations was of interest, but due to a large variance and relatively small mean difference, inclusion in the model could have been attributed to chance and chance alone.

Cantrell and colleagues (2006) conducted a study wherein engineering design challenge activities supplemented the standard curriculum, and student performance was compared to statewide statistics on the standardized tests. Cantrell's study concluded that engineering modules reduced achievement gaps of most ethnic minority groups. This study indicates ethnic minority groups underperformed their majority peers. This difference, noted in mean scores, was not statistically significant. Change over time does not support Cantrell's finding that the achievement gap was reduced, but it does suggest that the achievement gap was not increased significantly.

Weir (2004) differentiated data based on student groups by considering an academic top half and an academic lower half in a university engineering course. Her conclusion was that the upper half improved significantly ($p < 0.05$), while the lower half was not significantly ($p > 0.10$) different between the pre and posttest measures. Using science, math, and communication GPA as indicative of students' academic nature, students improved slightly more over time if their GPA was higher. This lends some support to Weir's conclusion, but differences based on GPA over time were very small and could be attributed to chance and chance alone.

Two of the five CM3 subscales of mental motivation significantly improved model fit. Knowledge of a student's creative problem solving score was a statistically significant predictor of achievement outcome. This positive correlation indicated students with a higher score on creative problem solving are more likely to score higher on the achievement test. Cognitive integrity was included in the model but was not statistically significant as a predictor. The small correlation and high variance suggests this predictor may have been attributed to chance and chance alone.

Mental Motivation

Mental motivation was measured by five subscales: mental focus, learning orientation, creative problem solving, cognitive integrity, and scholarly rigor. Mental focus was correlated with math and science GPA. Students scoring higher in math GPA showed a positive correlation with an increased mental focus score of approximately 2.5 points (scale 0-50) per GPA point. Correlation with science GPA was positive and of greater magnitude, approximately 3.5 points (scale 0-50) per GPA point. Interpretation of the CM3 scales used a categorization of 10 point blocks ranging from 0-50. Mean mental focus scores ranged from 27.27 in October to 27.54 in April. Scores ranging from 20-30 were considered “ambivalent” while scores in the 31-40 category were “somewhat disposed” (Insight Assessment, 2006). Thus, the practical significance of this correlation with science and math GPA is that higher GPA students tended to be categorized as “somewhat disposed” to being diligent, focused, systematic, task-oriented, organized, and clear-headed. Their lower GPA peers tended to be “ambivalent.”

Mental focus changes over time were negatively correlated with science GPA, meaning the initial score differential (between higher and lower science GPA students) was decreased over time. This statistically significant reduction of the mental focus gap between higher and lower GPA students held a practical significance as mid and high GPA students showed a small decrease in mental focus, while low GPA students showed a more dramatic increase in focus over time. Math and communication GPA had a positive correlation with mental focus indicating that students with higher GPAs tended to score slightly higher on the mental focus scale. Math and communication GPA interactions with time were not significant but were slightly negatively correlated which indicated that the mental focus gap was slightly reduced over time.

Learning orientation and cognitive integrity were not significantly correlated with cumulative GPA or individual GPAs for math, science, or communications. Slightly positive correlations were noticed with science GPA. Learning orientation was slightly positively correlated with math and communication GPA while cognitive integrity was slightly negatively correlated. Students began the semester with a score of approximately 32 and 33 (scale 0-50) in learning orientation and cognitive integrity, respectively. This indicates students were “somewhat disposed” to desire an increase in their knowledge, skill base, truth seeking and open-mindedness (Insight Assessment, 2006). Small, but not statistically significant, increases over time were observed. No significant correlations were discovered with GPA or GPA interacting with time. This indicates that regardless of GPA, students were equally likely to be interested in increasing knowledge and skill with a fair-minded perspective. A lack of correlation with GPA and time as an interaction factor indicates students did not change over time related to their GPA.

Creative problem solving was positively correlated with science GPA. Students with higher GPA in science tended to have a higher creative problem solving score, approximately 2.25 points (scale 0-50) higher per point on the GPA scale. Mean creative problem solving scores in October were 29.27, and statistically significant gains by April yielded a mean of 31.39. While 2 point gains held questionable practical significance, the average student did transition from “ambivalent” to “somewhat disposed” to having an increased tendency to approach problem solving with innovative or original ideas and solutions (Insight Assessment, 2006). A slight negative correlation was observed with math while a slight positive correlation was noted with communication GPA. Gains over time were not correlated to any of the GPA data, which, indicated that students, regardless of GPA, tended to increase over time on a similar slope.

Scholarly rigor was positively correlated with science GPA. Students with higher GPA in science tended to score higher in scholarly rigor, approximately 1.75 points (scale 0-50) higher per point of GPA in science. Slight positive correlations with math and communication were observed. Change over time was not statistically significant, nor was it correlated with GPA. Thus, student growth over time was unrelated to GPA in science, math, or communications. Student mean scholarly rigor scores in October were 26.27 which increased, but not significantly, to 27.76 in April. This indicated students were “ambivalent” in their disposition to work hard to interpret and achieve a deeper understanding of complex or abstract material (Insight Assessment, 2006).

Knowledge of a student’s status as an underrepresented population in engineering and technology education improved model fit statistically for each outcome considered. While this predictor significantly improved the model, it was not a statistically significant predictor. For each outcome considered, the inclusion of this predictor could be based on a mean difference and variance resulting from chance and chance alone.

Supporting the existing literature base (Dally & Zhang, 1993; Dunlap, 2005; Griffith, 2005; Lentz & Boe, 2004; Ricks, 2006; Rogers, 2005; Romero et al., 2006; Roselli & Brophy, 2006; Weir, 2004), attitude related scales measured pre and post did show improvement. In each of the five subscales of mental motivation, mean scores increased. Mental focus and creative problem solving mean scores improved significantly over time.

Validity

Internal and external validity were of critical importance to research. Internal validity referred to the "…level of certainty that the experimental treatment has a causal influence on the dependent variable" (Gall et al., 1999, p. 235). While this research study was of a correlational design rather than experimental, internal validity concerns were still addressed where appropriate. External validity, according to Gall et al., was "…the extent to which the experimental findings can be generalized beyond the research sample to other groups" (1999, p. 235).

Internal

Internal threats of history, maturation, testing, instrumentation, statistical regression, differential selection of participants, mortality and selection-maturation are typical experimental study concerns (Gay & Airasian, 2000). Correlation studies focus on predictors and outcomes without attempting to infer causality, yet, a few of the internal validity issues remain appropriate to address. Pertinent interval validity concerns include testing, instrumentation and mortality.

Testing was conducted in early October, mid-December, and late April. By spanning a few months between each test administration, the impact of test sensitization was less likely to affect student scores. The CM3 representatives stated in a phone conversation that the instrument may be administered in this study's schedule with minimal concerns of test sensitization.

Instrumentation was addressed as a concern in achievement and mental motivation instruments differently. The achievement test was piloted a year prior to the study, and three versions were developed from the pilot. To minimize the effect of differences between each version, all three test versions were administered during each testing visit. At the conclusion of the study, each student had taken each version, but not in the same order. Initial distribution of the tests was at random, and which version the student received at the next administration was also random. The CM3 was administered three times to the students without instrument change, as confirmed appropriate with Insight Assessment.

Participant mortality was a notable phenomenon that occurred in this study. Fifty-three students began this study, and 12 (22%) dropped before the study was complete. Study participants were limited to students who maintained enrollment in the selected course, and, therefore, when students withdrew from the course, they, by default, withdrew from the study. According to conversations with district administration, the school was noted as being a "transient" district where students often moved during the school year. This course was an elective, and if students required another course to graduate, they were removed at semester break and placed in the required course. Due to the safety concerns, few students enrolled as the year progressed, and, therefore, enrollment tended to drop rather than remain consistent. Table 9 (shown earlier) compares the demographic data on student enrollment over time. Mortality of students enrolled in each of the two sections of this course was comparable with section one losing seven students and section two losing five students. Female participants did not withdraw from the study while male mortality accounted for the entire change in sample size. Ethnic status data were not collected until April, and, therefore, students who withdrew were not identified. This lack of data limited conclusions drawn on a relationship between morality and ethnicity. Mean cumulative GPA was computed for student participants at each time point (see Table 9). A statistically insignificant ($p = 0.808$, refer to Table 10) difference in GPA per time point resulted from a disproportionately higher dropout rate from students with low GPA.

External

External threats of pretest-treatment interaction, selection-treatment interaction, multiple treatment interface, specificity of variables, treatment diffusion, experimenter effects, and reactive effects are typical experimental study concerns (Gay & Airasian, 2000). Correlation studies focus on predictors and outcomes without attempting to infer causality, yet, a few of the external validity issues remain appropriate to address in this study. Pertinent interval validity concerns include selection-treatment, specificity of variables and reactive arrangements.

Selection-treatment interaction was considered purposefully in this study. While a treatment was not administered as it would be in an experimental study, the effects of participating in this course did potentially interact with the selection of students. Technology education students represent an academically diverse group of students. This study purposefully was set in a classroom wherein participants ranged in academic background in order to represent the diverse national population.

Specificity of variables was a serious concern in this study. Operationalized definitions of engineering design are provided as a contextual description of the research setting with qualitative methodologies employed early in the findings section. Definitions of engineering design, its iterative processes and their application in the technology education classroom are far from a standardized practice. Thus, documentation of observations and student data were critical in providing opportunities for generalizing the research findings to a larger audience given specific definitions of operationally ambiguous practices. The achievement test development was outlined in the methodology section, and the pilot, as well as the three test versions, are presented in the appendix. The CM3 validity and reliability data were presented briefly in the methodology section, and further details are available in the appendix.

Reactive arrangements may have influenced achievement and mental motivation data gathered. When the researcher was introduced to the student participants, an overview of this study was delivered. During this overview, the researcher communicated the importance of this study and attempted to establish a rational for students, motivation to participate in this research effort. Inadvertently, the researcher may have contributed to a reactive arrangement where students felt special because they were in an important study. The Hawthorne effect may have some level of impact on data gathered as students may have made a greater effort during data collection based solely on their knowledge of being studied. This effect may have changed over time as the researcher only established the importance of this study with the students during the first meeting (and testing), not in subsequent test administrations. Achievement test scores may have been overly inflated in October, as a drop was noted to December before a score gain in April. Generally, similar trends existed for the CM3 scores.

Implications

Implications for Technology Education

The field of technology education embraces the importance of technological literacy and caters to an academically diverse audience of student learners. Integrating engineering design into the curriculum addresses the Standards (STL) and broadens student understanding of our designed world. This study provided an approach to operalizationalizing the definition of engineering infused into technology education. In this example, students participated in two corequisite courses. Each course was essentially a standalone course in the fall, one focused on engineering as applied physics and the other material (typically metal) fabrication techniques. The set of learning experiences implemented in the fall in both classes prepared students with foundational knowledge from which they could begin to design, fabricate, test, and redesign during the spring term. The use of electric cars as a design challenge provided a problem on which engineering design was applied.

Results from this study indicate that while achievement gaps exist, these gaps are not widened while introducing engineering design concepts into a technology education classroom. Special education students performed poorly on the achievement test as did lower science GPA students, however, growth among these groups was not statistically different than their peers. Thus, engineering design infused into technology education does not disadvantage student growth as measured by an achievement test over time.

Mental motivation was measured in five subcategories. In one case (mental focus), an interaction was discovered between time and a GPA (science). This interaction was negative, indicating that initial differences among higher and lower GPA students was reduced over time, effectively reducing the gap between higher and lower GPA students. While the trend of reducing the gap for lower achieving students was encouraging, this indicated that high achieving students demonstrated a drop in mental focus over time. According to the instructors of the course, students who were lower achieving may discover the relevance of the academic material when presented with an application opportunity. This discovery of relevance may motivate them to engage in higher levels of mental focus. On the other side of the academic spectrum, higher achieving students may exhibit characteristics of boredom as the pace of the course is perceived to be less challenging than is appropriate for their level. The other four subscales, neither GPA in math, science, or communication impacted growth over time.

This indicated to the field that higher and lower achieving students (as measured by GPA) did not have statistically different growth patterns over time. Therefore, lower GPA students are likely to improve in learning orientation, creative problem solving, cognitive integrity and scholarly rigor as their higher achieving peers.

The teaching methodologies described herein have been determined to be successful by the teachers and their administration. Teaching methods were observed and documented for replication and generalizability, but were not measured or tested. This research site provided an environment where two teachers collaborated, each responsible for his content. In this setting, the teachers shared a common goal, but each took responsibility for a separate portion of the curriculum. Mr. Brewer taught engineering as applied physics focusing on small projects in the fall to provide a foundation for the larger design challenge in the spring. Mr. Rivet taught fabrication techniques, including welding, cutting, fasteners, drilling, and bending. His primary focus was metal working, but he included other materials as well. Mr. Rivet's fall semester was typical of many technology education (and industrial technology education) laboratories focused on skill development. The spring term provided students with the engineering design challenge and a foundation of fabrication and design skills from which they could develop a solution.

While two teachers combined foci and efforts, the researcher believed the pedagogical skill set and educational methodologies employed during this study are not based on an interaction between two teachers, but rather a simple sum of two parts. In conversations with the instructors, they concurred that one teacher could comfortably handle the responsibilities of teaching metal fabrication and engineering as applied physics. This conversation naturally stemmed from the impending retirement of Mr. Rivet and, consequently, Mr. Brewer's pursuit of certification of a career and technical endorsement. Observations of classroom teaching support the premise that one teacher would be capable of managing the responsibilities which were, in this study, split between two. This teacher would need to be certified and competent in teaching material processing, as well as engineering design concepts. Thus, conclusions and findings from this study are not hinged in the synergistic efforts of two teachers. Rather, they were based on two content areas focused on teaching students to develop a solution to a common problem. Each content area provided skills and abilities which facilitated a synergistic effect within the student to utilize an engineering based approach in a technology education environment.

Transitioning from the two teacher classroom in this study to the more typical one teacher technology education environment will hinge, in part, on teacher knowledge. Skills required are related to the design problem presented to the students. In this particular case, welding, and material fabrication skills were appropriate to develop a solution, as well as the ability to apply physics concepts to real world problems. The skills used by the students in solving the problem were a subset of the teacher's skills, and, therefore a different engineering design challenge would require different teacher knowledge. Thus, the teacher's skills and knowledge should align with potential avenues for solving a design challenge prior to its selection for classroom use. Content for teacher professional development may be driven by a specific domain of design challenges or, conversely, the teacher's skill set may drive their choice of design challenges in their classroom. Thus, a level of teacher experience is requisite in the areas relevant to designing and building solutions to problems.

In taking full advantage of the engineering design process, an understanding of math and science (physics in this study) was necessary. Technology education teachers should pursue a strong background in mathematics and science. Physics was the most overt science content exploited in this study, however, other science principles may be appropriate. As an example for this design challenge, a teacher of fluid dynamics may have lead to developing lessons specific to aerodynamics. This may have resulted in students' designing their bodies and frames differently to optimize speed. Therefore, a broad teacher understanding of math and science will provide opportunities for deepening student understanding of the system behaviors through explanation and relevant hands-on application. While naive understandings of math and science will limit technology teacher potential, a lack of understanding does forecast impending failure. Teachers may choose a few aspects of a particular engineering design challenge with which they are (or will become) familiar, and other aspects may be left to trial and error approaches. Where areas of teacher weakness exist, opportunities for professional development abound. However, in the busy teacher work day, other support may be found through collaboration with science and math teachers, industry professionals, higher education partnerships and knowledgeable parents.

Implications for Engineering Education

The engineering community has a dynamic and critical relationship with society. As technology education, with its foothold in the American school system, entertains the notion of making cross-curriculum connections with engineering, the potential develops for defining relationships between engineering and technology education. Gorham and colleagues (2003) described a synergistic relationship between engineering and technology education toward a common goal of technological literacy. The engineering community is concerned with the technological literacy of society, as well as maintaining (and improving) the pipeline from high school graduation to engineering school entrance. “An engineering-led effort to increase technological literacy could have significant, long-term pay-offs, not only for decision makers in government but also for the public at large” (Pearson & Young, 2002, p. 112). Including engineering in high school will certainly increase the number of students to the field of engineering. All current students and future community members are directly or indirectly impacted by decisions of engineers. As high school students begin to understand the critical lens used by engineers to make decisions, they, too, will deepen their understanding of the world shaped by engineers.

Implications for Engineering Design Challenges

Engineering design challenges are one avenue for facilitating the understanding of engineering through hands-on application. Technology education historically has been the window through which students apply what they have learned in a relevant hands-on fashion. Utilizing the tools specific to engineering in combination with technology education's typical hands-on approach will facilitate expanding students' technological literacy thereby addressing the STL standard nine. Students in technology education typically use many tools such as material processing equipment, computer aided design software and teamwork to solve problems. Engineering may add additional tools to the experience in the classroom. The extent to which engineering design is applied in the classroom is related to the developmentally appropriate nature of student learning just as the decision to use power tools (and which ones) in material processing problems. These engineering tools and processes may be developed into the technology education curricula for research and testing.

This study suggested six critical elements of engineering design: problem definition, development of solutions, analysis/modeling, experimentation, decision making and teamwork. These six iterative elements were derived from a review of literature and became a lens through which the design challenge was viewed. Students participated in various activities which focused their efforts in developing skills in each of these six areas. Evident in the observations was the theme of student transition from teacher driven problems with narrow boundaries to student driven problem definition with wider boundaries. In this research, projects started as small individual activities early in the fall term. As the semester progressed, projects became more complex, and a necessity for teamwork developed. Each activity in the fall provided students with experience and skills in areas of engineering design and material fabrication. This preparation provided a solid foundation for the spring challenge.

The magnitude of designing and building an electric race car was a large scale project in this study. The methodologies utilized in this classroom spanned two periods over one year. The fall was devoted to learning fabrication skills and engineering design applicable to the spring challenge. Teaching pedagogy of preparing students with a series of small learning experiences which increase in intensity and complexity may be scaled to fit a different context. Classrooms where smaller engineering design challenges are implemented may still adopt the same teaching methodology. This means identifying a series of learning experiences which will promote successful completion of the engineering design challenge. These small activities will be specific to the coming challenge and, therefore, may be adapted to fit a variety of different schedules. Smaller activities must provide relevant practice in engineering design and requisite material processing skill development. As noted in this study, smaller activities should begin as primarily teacher directed (and defined) and transition to student directed and defined learning experiences. Teamwork was developed in this study as a transition from individual projects to smaller, and then larger, group experiences, thus, allowing students to practice interacting with smaller teams first.

Recommendations

Recommendations for Teachers

Secondary technology education teachers should infuse engineering into their curriculum as suggested by the STL. The development and implementation of engineering design related curricula into a technology education environment can be done in such a way that all students, ranging from academically struggling to academically successful, can grasp the concepts presented. In this study, a comprehension of science (measured by GPA in previous courses) was a statistically significant trend that influenced achievement success and mental motivation. Math and communication skills also tended to exhibit a slightly positive correlation with achievement and mental motivation.

Technology teachers need to be prepared to reinforce absent science concepts when delivering an engineering design challenge which are relevant to the task at hand. The introduction (or review) of relevant math and science concepts may be in a series of small activities that build up to the challenge or in a “just-in-time” format to meet the needs of the learners. Math and communications are important academic areas, and, generally, showed positive correlations with outcomes measured in this study. The correlations with math and communications were not statistically significant which may be related to the focus of this particular design challenge, not necessarily representative of all design challenges.

Teachers and their supportive administrations should recognize that using technology education as a venue for teaching engineering design does not serve to extend the achievement or mental motivation gaps present as students transition through a design challenge. Student motivation was critical to maintaining and managing a successful learning environment. Motivated students tend to make a more diligent effort to acquire new material and apply their conceptual understanding to problems at hand. In this study, students formally began designing their solutions to the engineering design challenge in

January. As early as March, student teams were beginning to race their cars. Races were typically hosted by local schools and were held nearly every weekend. This schedule impacted learning in the classroom by facilitating an iterative design process. Students would typically race their cars on Saturday, make improvements or modifications during the week and race again the following week. This constant form of testing allowed teams to make changes to their car and discover firsthand the results of those modifications. By virtue of the tight timeframe, teams generally raced the first few races without a car body. But, when the car was functional, they focused efforts of developing an aerodynamic body. Thus, inadvertently, students experienced the impacts of each improvement to their cars as the designs evolved over time. This iterative process provided learning opportunities, but also motivated students through the excitement of testing their renewable energy vehicle. Therefore, as teachers incorporate design challenges, students need the opportunities to engage in the iterative process of design, test, redesign, and test again for the purpose of discovering the impact of their modifications, as well as being motivated by successful experimentation.

Recommendations for Teacher Education

Teacher educators should develop an understanding of engineering design in order to develop a level of efficacy in creating and delivering curricula to high school students. This understanding may be fostered through professional development experiences and preservice education focused on addressing the STL. Research is necessary to determine what engineering design content is relevant for high school teachers to be able to perform as curriculum developers, implementers and evaluators. This study proposes six elements of engineering design in an iterative process, but other competing approaches exist. Experimental determination of the most appropriate approach to engineering design can serve as the foundation for developing a teaching workforce with capacity for implementation. Using a tested approach to engineering design will naturally lead to inquiry on best practices for implantation at the high school level. Studies identifying best practices will inform professional development of current and preservice teachers.

Research should determine the level of pedagogical content knowledge requisite to teaching engineering design. Engineering design is a process for addressing challenging problems and may be thought of as a lens through which the world (and its problems) is viewed. In considering implications for teacher education, we must address the following question: How do we best prepare teachers to utilize this approach as a methodology in their classrooms?

Measurement of student learning is of critical importance. Research measuring student learning should be linked to professional development efforts. Teachers pass through three stages of professional development proposed by Glickman and colleagues (2004): orientation, integration, and refinement. As professional development efforts facilitate infusing engineering design into technology education, it should be recognized that teachers need support beyond a brief workshop. Teachers in the field will need a support network to reinforce integration of new concepts and hone their teaching and curriculum development skills in an ongoing refinement effort.

Recommendations for Researchers

Further research should be conducted to better assess student achievement change over time. This study showed no significant gains in achievement, and, therefore, conclusions and implications on achievement change should be conservatively considered.

Additional research should investigate potential correlations between GPA as an indicator of academic success and achievement and mental motivation for underrepresented populations. In each outcome, this status was important to control for, but differences were not statistically significant. This recurrent theme necessitates further investigation.

Clarity of operationalizing engineering design appropriate for technology education is an area for future research. Engineering design was defined for this study through a synthesis of relevant literature and research site practice, influenced during professional development by the researcher. Presented in the findings section are data describing the context of this research. The developmentally appropriate nature of determining the extent to which engineering design related activities and lessons are utilized in this eleventh grade classroom was based solely on the participating teachers' discretion. Therefore, future study may enhance the field's understanding of what constitutes developmentally appropriate engineering design curricula in a technology education environment.

This study established correlations between predictors and outcome variables but must stop short of inferring causality. Additional research should pursue casual effects based on this research foundation. Experimental designs with control and treatment group should be conducted in a variety of classrooms. Engineering design presented here was applied to the Electrathon America challenge and could be extended to various other engineering problem solving opportunities. These experimental designs should vary in duration, from unit sized formats lasting a few weeks to semester long challenges such as this one. This study was potentially unique in that two teachers were participating under one syllabus, teaming their efforts focused on a common goal. While some school districts offer incentives for teachers to develop their cross-curriculum connections in a team approach, many do not. Experimental studies should be conducted to demonstrate differences between team teaching environments and more typical one-teacher classrooms. Longitudinal data may be gathered following students who participated in a design challenge study. Students in the control and treatment groups may be followed over a number of years to assess the impact in post secondary education and career choices.

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APPENDICES

Appendix A

Course Syllabus

COURSE SYLLABUS

COURSE TITLE **INDUSTRY & ENGINEERING SYSTEMS** COURSE NUMBER **XXXX**
DEPARTMENTS **SCIENCE ELECTIVE AND INDUSTRIAL TECHNOLOGY ELECTIVE**
AREA OF STUDY **SCIENTIFIC, TECHNICAL AND LOGICAL PROCESSES**
LENGTH OF COURSE **1 YEAR** NO. OF CREDITS **2.0** GRADE LEVEL **11-12**
PREREQUISITE **JUNIOR STANDING OR CIM CERTIFICATE** CREDIT BY EXAM **NO**

COURSE DESCRIPTION:

GENERAL: With the knowledge gained throughout this course the students will do a large number of projects to develop and enhance their engineering, designing, industrial technology, fabrication, and construction skills. Much of the emphasis of this course will be related to transportation and metals technology. In the course students will design and construct hands on projects such as model: magnetic levitation vehicles, solar vehicles, and bridges. Students will also learn the skills of welding, machining and other metals technology skills. Students will build electric motors along with other projects that teach practical engineering. Students can also construct school related items and other items for their personal use. A major project will be to construct and race ultra efficient and ultra light one-person vehicles. We will take these Electrathon vehicles around the Northwest and enter races against other high school students and adults. In their last semester of this 2-year program students will do a major individual application of what they have learned or what is called a "senior project".

SCIENCE: Physics itself is the study of how things around us in the real world work and why they do the things that they do. Engineering is largely the application of physics. The course will use mostly hands on activities to explore and discover the major concept of physics dealing with motion, forces (such as gravity), and simple machines. We will also study areas of electricity, heat, magnetism, aerodynamics, and air pressure. This course will introduce many concepts of engineering and the designing of systems. The student will learn mostly by doing small group projects or labs. We will then apply this knowledge to real life activities.

INDUSTRIAL TECHNOLOGY: In this part of the course, we will be using mostly metals but to some degree all of the technology lab facilities here at Porter Valley, including mechanics, electronics, drafting and woods. We will learn to use these facilities to design, construct, and test some of our major projects. Emphasis will be placed upon machine and tool safety, individual skill building, proper tool selection and setup, and operation. The labs will provide a bridge between what we learn in the classroom to practical applications in a real world setting. We will apply technology, and the skills we have learned in math, science and communication to several major projects.

TEXT:

(1) Teacher developed projects and lab activities.
(2) Teacher developed description of physic and engineering concepts utilized in projects.
(3) Supplemented with material from many other sources.

PAT TIME
Brewer--Second half of period 5 in upstairs office in metals
Rivet--First half of period 8 in downstairs metals office

NEW GRADUATION REQUIREMENTS
During this course students will be given the opportunity to meet all of the new state graduation requirements of: 1) Education Plan and Profile 2) Career Related Learning Standards 3) Career Related learning Experiences and 4) Extended Applications.

COURSE CALENDAR
Students work on projects through out the year. They will be learning skills by doing small projects until winter break and then on to the Electrathon vehicles in January with races starting in March and running through September. During the spring there will be other small projects.

Starting with student's graduating in 2007, to earn CAM students must meet **five state-level criteria**. These criteria are described below. This is in addition to MEETING ALL REQUIREMENTS FOR THE SPECIFIC CAM YOU ARE PARTICIPATING IN.

1) EDUCATION PLAN AND EDUCATION PROFILE:
All students must develop both and Education Plan and an Education Profile. These guide students' learning, provide ownership and relevancy for learning, reinforce academic achievement, provide direction toward post-high school goals, and allow students to monitor their progress toward meeting: CIM standards, diploma and CAM requirements, college/vocational entrance requirements, and other accomplishments. The next four criteria are all linked to the education plan and profile, making them the "cornerstone" of all requirements.

2) EXTENDED APPLICATIONS:
Students must meet the performance through a collection of work. They do this by "applying academic and career-related knowledge and skills in new an complex situations appropriate to the student's personal, academic and evolving career interest and post-high school goals."

3) CAREER-RELATED LEARNING STANDARDS:
Students must demonstrate that they achieved the performance standard in all of the following
six areas (6):

- -Personal Management
- -Problem Solving
- -Communication
- -Teamwork
- -Employment Foundations, and
- -Career Development

4) CAREER-RELATED LEARNING EXPERIENCES:
All students must participate in two (2) career-related learning experiences as outlined in their education plan; identify learning outcomes; and reflect on their learning. These experiences should connect classroom learning with real-life experiences in the

workplace, community, or school relevant to their personal, academic and evolving career interests and post-high school goals

5) CIM STANDARDS:

Students must complete five of the CIM components to earn a CAM. Requirements are:

a. pass the CIM reading test
b. pass 3 CIM speaking work samples
c. pass 3 CIM writing work samples
d. pass the CIM math test--OR--pass 2 CIM math work samples, and
e. pass the DIM science test--OR--or pass 1 CIM science work sample in all 4 areas.

SPECIFIC REQUIREMENTS FOR THE INDUSTRY AND ENGINEERING CAM ARE:

a) "B" average GPA in both years of the actual CAM class.
b) A research or senior project that includes at least four (4) pages of text. This written portion must earn at least a 4 on all writing standards. (due MAY 18)
c) An oral presentation of at least 5 minutes if done individually (12 if a team of 2). This again must earn at least a four (4) on all speaking standards. (evening MAY 17)
d) Student must earn a standard diploma.
e) Student has earned at least a 2.0 GPA overall in their high school years.
f) The student has taken a drafting course and earned at least a "C"
g) Students must do a successful job shadow their first year (at least 4 hours)
h) One to four additional job shadows of at least 30 hours total duration

   --or--

   a CAM related service-learning project approved by the instructors
i) Satisfy the "Skills Sheet" by having at least 5 skills at the "advanced" level, another 5 at "intermediate" level, and another 15 at the "introduced" level.
j) Use of Technology: If a specific teacher feels that their specific project met this requirement then that teacher can sign off this checklist requirement

Appendix B

Technological Literacy Literature

Table B-1

Summary of Technological Literacy Literature

Reference	Need for	Lack of	Inclusion of engineering by name	Support of standards
Weber, 2005	X	X		X
Meade & Dugger, 2005	X	X		X
Russell, 2005	X	X	X	X
Spoerk, 2005	X	X	X	X
Engstrom, 2005	X		X	X
Frank, 2005			X	
Rogers & Rogers, 2005	X		X	X
McKenna & Agogino, 2004	X		X	X
Shumway & Berrett, 2004	X			X
Meade, 2004b	X	X		X
Meade & Dugger, 2004	X	X		X
Lentz & Boe, 2004	X			X
Rose et al., 2004	X	X	X	X
Meade, 2004a	X	X		X
Britton, De Long-Cotty, & Levenson, 2004	X	X		X
Post, 2004	X		X	X
Bengston, 2004	X		X	X
Pearson, 2004	X	X	X	X
Meade, Delany, & Dugger, 2004b	X			X
Meade, Delany, & Dugger, 2004a	X			X
Morrow, Robinson, & Stephenson, 2004	X	X	X	X
Shackelford, Brown, & Warner, 2004	X			X
Harpine, Hickey, & Whiting, 2004	X		X	X
Berry & Detamore, 2003	X			X
Daugherty, 2003	X			X
Russell, 2003a	X			X
Dugger, Meade, Delany, & Nichols,2003	X	X		X
Reeve, Nielson, & Meade, 2003	X			X
Bybee, 2003b	X	X		X
Barnette, 2003	X		X	X
Bybee, 2003a	X	X	X	X

(*table continues*)

Reference	Need for	Lack of	Inclusion of engineering by name	Support of standards
Dugger, Meade, Nichols, & Delany, 2003	X		X	X
Russell, 2003b	X			X
Gorham et al., 2003	X		X	X
Grimsley, 2002	X		X	X
Bell & Rabkin, 2002	X	X	X	X
Reeve, 2002	X	X	X	X
Poertner, Summer, Tsosie, & Zak, 2002				X
Starkweather, 2002	X	X	X	X
Gorham, 2002	X	X	X	X
Rose & Dugger, 2002	X	X	X	X
Martin, 2002	X	X		X
Whiting, 2002	X		X	X
Custer, 2001	X			X
Dugger & Naik, 2001	X			X
Newberry, 2001	X		X	X
Hook, 2001	X			X
Kanne, Mino, & Novak, 2001	X	X	X	X
Reeve, 2001	X			X
Sumner, 2001	X			X
Dugger, 2001	X			X
Dugger, 2000a	X	X		X
Bybee & Loucks-Horsley, 2000a	X		X	X
Bybee, 2000	X	X	X	X
Colaianne, 2000	X		X	X
Wulf, 2000	X	X	X	X
Bybee & Loucks-Horsley, 2000b	X			X
Dugger, 2000b	X			X
Smith, 1998	X			X
Byars, 1998	X	X	X	X
Altice & Dugger, 1998	X			X
Laurent, 1997	X	X	X	X
Kinser, Dugger, Newberry, & Singletary 1997	X			X
Dugger, 1997	X	X		X
Singletary & Altice, 1997	X	X	X	X
Totals (n=66)	**64**	**28**	**33**	**65**

Appendix C

EC2000 and STL Compared

Concepts and Principles	*Engineering Criteria 2000* (Post-Secondary)	*Standards for Technological Literacy* (K-12)
Understand and use mathematics, science, and technology	ABETA	STLS3, STLS4, & STLS7
Understand technological knowledge	√	STLS1 & STLS2
Understand the history of technology	√	STLS7
Understand the historical significance of previous advances in technology and engineering	√	STLS3 & STLS7
Understand about engineering and technology in society	ABETF, ABETH, & ABETJ	STLS 4, STLS5, STLS6, & STLS7
Understand systemic principles	ABETC & ABETH	STLS11, STLS12, & STLS13
Understand ecological principles	ABETJ	STLS5
Use and recognize inquiry skills, apply knowledge in retrieving information, and recognize and analyze major limitations in the usefulness of information	ABETB, ABETF, ABETG	STLS3, STLS10, STLS13 & STLS 17
Understand and use abilities of engineering design • Define a problem • Brainstorm, research, and generate ideas • Identify criteria and specify constraints • Develop and propose designs and chose between alternative solutions • Implement a proposed solution • Make a model or prototype • Evaluate a solution and its consequences • Refine the design • Create or make the design • Communicate the processes and results	ABETB, ABETC, ABETE, ABETG, & ABETK	STLS8, STLS9, STLS10, &STLS11
Identify, formulate, and solve engineering problems	ABETE	STLS8, STLS9, STLS10, & STLS11
Employ tools and equipment and use appropriate tools and techniques	ABETK	STLS1, STLS11, & STLS12
Understand properties of objects and materials	√	STLS2, STLS15, STLS18, STLS19, & STLS20
Understand about risks and benefits of design solutions	√	STLS2, STLS5, & STLS13
Understand resources: ➢ Understand properties of earth materials, such as building materials & sources of fuel ➢ Understand resources and human use	√	STLS2, STLS14, STLS15 STLS16, STLS17, STLS18 STLS19, & STLS20
Work as a team or individually to solve problems	ABETD	STLS2, STLS11, STLS12, & STLS13
Assess impact and consequences of products and systems and assess impact and consequences of actions.	√	STLS13
Communicate solutions in portfolios, design sketches and drawings, journals, logs, multi-media presentations, and audio-visual presentations	ABETG	STLS12 & STLS17
Recognize the need for, and ability to engage in life-long learning	ABETI	√

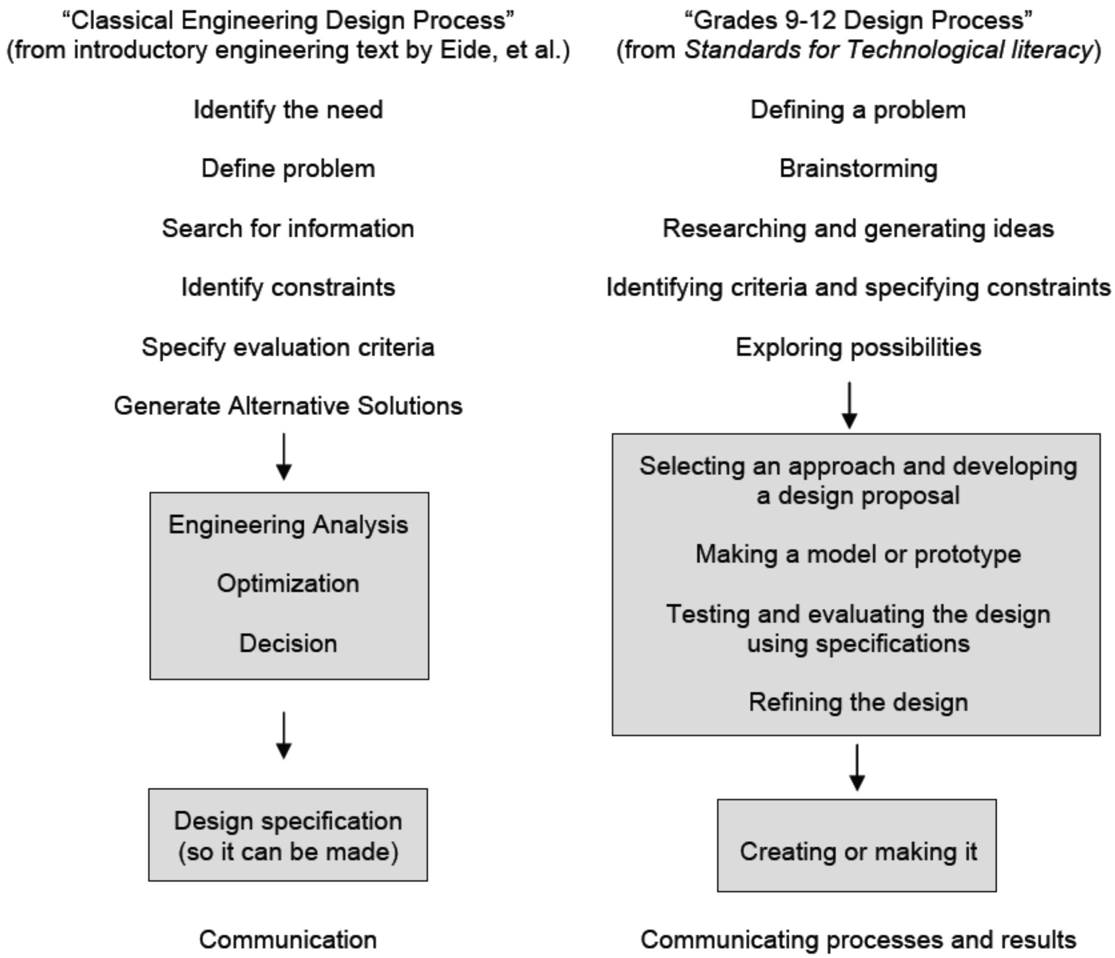
Table 2. A table depicting some of the major concepts and principles covered in technology education courses and recommended engineering accreditation criteria.

Key: A code sequence of ABETA through ABETK correlates to the ABET's outcomes a through k (in Criterion 3 of Engineering Criteria 2000*), while STLS1 through STLS20 correlates to the ITEA's* Standards for Technological Literacy. *A check mark, √, refers to the topic being mentioned or covered in some manner, but it may not be directly stated.*

Gorham et al. (2003, p. 98)

Appendix D

Comparison of Design Processes



Comparison of an Introductory Engineering Design Process with the Standard 8 Design Process (Hailey et al., 2005)

Appendix E

Electrathon America Overview

Electrathon America Mission Statement: To create and develop a sport that improves public awareness and understanding of electric vehicles through continuously improved vehicle and event rules.

OBJECTIVES OF ELECTRATHON AMERICA COMPETITION:
ELECTRATHON is a type of ELECTRIC MARATHON in which the winner is determined by how far you go in a certain time with a given amount of battery power. ELECTRATHON AMERICA class competition uses specific design rules to ensure safe and fair competition. ELECTRATHON AMERICA events are held around the country and is an exciting new environmentally progressive sport.

To drive electrically powered vehicles as far as possible for one hour on a closed loop course using limited electrical energy.

To provide a forum where skill and ingenuity may be displayed, compared and tested.

To improve public awareness and understanding of efficient alternative electric vehicles.

To create an affordable sport defined by established rules in which groups and Individuals can participate competitively and safely.

For more information: http://electrathonamerica.org

(Electrathon America, 2007)

Appendix F

Pilot Study IRB Approval

Utah State UNIVERSITY

INSTITUTIONAL REVIEW BOARD OFFICE
9530 Old Main Hill
Military Science Room 216
Logan UT 84322-9530
Telephone: (435) 797-1821
FAX: (435) 797-3769

USU Assurance: FWA#00003308
Protocol # 1838

SPO #:
AES #:UTA00

MEMORANDUM

TO: Kurt Becker
Nathan Mentzer

FROM: True M. Rubal-Fox, IRB Administrator True M. Rubal-Fox

SUBJECT: Achievement and Attitudinal Effects of an Engineering Design Challenge in Technology Education

Your proposal has been reviewed by the Institutional Review Board and is approved under exemption #2.

X There is no more than minimal risk to the subjects.
There is greater than minimal risk to the subjects.

This approval applies only to the proposal currently on file. **Any change in the methods/ objectives of the research affecting human subjects must be approved by the IRB prior to implementation.** Injuries or any unanticipated problems involving risk to subjects or to others must be reported immediately to the IRB Office (797-1821).

The research activities listed below are exempt based on the Department of Health and Human Services (DHHS) regulations for the protection of human research subjects, 45 CFR Part 46, as amended to include provisions of the Federal Policy for the Protection of Human Subjects, June 18, 1991.

2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (a) information obtained is recorded in such a manner that human subjects can be identified, directly or through the identifiers linked to the subjects: and (b) any disclosure of human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Appendix G

Porter Valley High School Participation Agreement

Porter Valley High School Participation Agreement

Students and Teachers attending Porter Valley High School have permission to participate in the research study to understand the extent to which a student's general academic success correlates with student achievement and mental motivation during an engineering design challenge.

I understand participation in this research study is entirely voluntary and my decision whether or not to provide permission for Porter Valley High School to participate will involve no penalty or loss of benefits to which students and teachers are otherwise entitled.

I furthermore understand that my decision to provide permission for Porter Valley High School students and teachers to participate does not obligate students or teachers to participate and that they are free to discontinue participation at any time without penalty or loss of benefits to which they are otherwise entitled.

I understand the Principle Investigator on this graduate student dissertation research study is Dr. Kurt Becker, and that he may be contacted at 435-797-2758 for more information regarding this study. If I have questions regarding the rights of research participants, I may contact the Utah State University Institutional Review Board at 435-797-1821.

My signature below indicates that:

- I have read and understand the information provided above, and that I am willing to provide permission for students and teachers at Porter Valley High School to participate in this research study.
- I may withdraw my consent at any time and discontinue participation at any time without penalty or loss of benefits to which students or teachers may otherwise be entitled.
- I will receive a copy of this form and the research proposal.
- I am not waiving any legal claims, rights or remedies.

______________________________	____________________
Print Name	Position
______________________________	____________________
Signature	Date

Appendix H

Pilot Study Letter of Information to Teacher

Date Created: May 30, 2007
USU IRB Approved 05/30/2007
Approval terminates 05/29/2008
Protocol Number 1838
IRB Password Protected per IRB Administrator

Letter of Information: Achievement and Attitudinal Effects of an Engineering Design Challenge in Technology Education.

Introduction/ Purpose Professor Kurt Becker in the Department of Engineering and Technology Education at Utah State University (USU) and Nathan Mentzer, Research Assistant, are conducting research to find out more about impacts of an engineering design challenge. You have been asked to take part because you are currently teaching an elective course which embodies the general characteristics of an engineering design challenge with 11th grade students.

The field of Engineering and Technology Education is currently in a state of transition such that engineering concepts are being infused into the technology education paradigm This transition necessitates redefinition of educational methodology appropriate for the future public school educators. This research will highlight one aspect of education; the engineering design challenge.

Procedures If you agree to be in this research study, you will be expected to assist in developing an achievement test which aligns with your classroom objectives. You will also be expected to administer this test on three occasions during the school year to the participating students. In addition to the measurement on achievement, you will be expected to administer a measurement of attitude, specifically motivation toward learning.

Risks/Benefits There is minimal risk in participating in this study. This research may benefit both the field of engineering and technology education and Porter Valley School District. The field may benefit by shedding additional light on the relationship between academic success and experience during an engineering design challenge. The school district will benefit through receiving quantitative knowledge of the impact of this course on students.

Explanation & offer to answer questions Nathan Mentzer has explained this research study to you and answered your questions. If you have other questions or research-related problems, you may reach Professor Kurt Becker at (435) 797-2758 or Nathan Mentzer at (435) 797-1796.

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only Dr. Becker and Nathan Mentzer will have access to the data which will be kept in a locked file cabinet in a locked room. A random code number will be assigned to each student replacing his/her name to match pre- and posttest scores, then code will be destroyed.

USU IRB Approval Statement The Institutional Review Board for the protection of human participants has approved this research study. If you have any questions or concerns about your rights, you may contact the IRB at (435) 797-1821

Kurt Becker, Ph.D., Principal Investigator	Nathan Mentzer, Research Assistant
(435) 797-2758	(435) 797-1796

Appendix I

Pilot Study Letter of Information to Students and Parents

Date Created: May 29, 2007
USU IRB Approved 05/29/2007
Approval terminates 05/28/2008
Protocol Number 1838
IRB Password Protected per IRB Administrator

Letter of Information: Achievement and Attitudinal Effects of an Engineering Design Challenge in Technology Education.

Introduction Professor Kurt Becker and Research Assistant, Nathan Mentzer of Utah State University (USU) would like your student to participate in a research study of engineering design challenges. In Mr. Brewer's class, "INDUSTRY & ENGINEERING SYSTEMS", your student has the opportunity to design and race electrathon cars. Porter Valley High School and USU have partnered to research your student's experiences and changes throughout the school year.

Procedures Your student will be expected to complete a 30 minute paper and pencil test. Questions on this test are multiple choice and ask about the physics being learned in this course. This is a pilot test and your student's participation will help further develop this physics test.

Risks There is minimal risk in participating in this study. Your student's performance on this test will not impact his/her class grade.

Benefits This research may benefit both the field of engineering and technology education and Porter Valley School District. The field will benefit by shedding addition light on the relationship between academic success and experience during an engineering design challenge. The school district may benefit through receiving quantitative knowledge of the impact of this course on students.

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the investigator and Nathan Mentzer will have access to the data which will be kept in a locked file cabinet in a locked room. Students will remain anonymous.

Statement of Study Director This research has been reviewed and approved by the Institutional Review Board for the protection of human subjects at Utah State University. I certify that the information contained in this form is correct and that we have provided trained staff to explain the nature and purpose, possible risks and benefits associated with taking part in this study and to answer any questions that may arise.

Kurt Becker, Ph.D.
Principal Investigator
(435) 797-2758

Nathan Mentzer
Co-Principal Investigator
(435) 797-1796

Appendix J

Letter of Information to Parents

Letter of Information: Achievement and Attitudinal Effects of an Engineering Design Challenge in Technology Education.

Introduction Professor Kurt Becker and Research Assistant, Nathan Mentzer of Utah State University (USU) would like your student to participate in a research study of engineering design challenges. In Mr. Brewer's and Mr. Rivet's class, "INDUSTRY & ENGINEERING SYSTEMS", your student has the opportunity to design and race electrathon cars. Porter Valley High School and USU have partnered to research your student's experiences and changes throughout the school year.

Procedures Your student will be expected to complete a 30 minute paper and pencil test three times this year. Questions on this test are multiple choice and ask about the physics concepts your student is learning in this course. Your student will also complete a short questionnaire asking about his/her interest in learning three times this year. The researcher will have access to your student's transcript.

Risks There is minimal risk in participating in this study. Your student's performance on this test will not impact his/her class grade.

Benefits This research may benefit both the field of engineering and technology education and Porter Valley School District. The field may benefit by shedding addition light on the relationship between academic success and experience during an engineering design challenge. The school district may benefit through receiving quantitative knowledge of the impact of this course on students.

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. Your student may refuse to participate or withdraw at any time without consequence or loss of benefits. To withdraw from participation, please contact Seymour Skinner, assistant principle; (877) 337-7247 or sskinner@portervalley.k12.nw.us.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the Dr. Becker and Nathan Mentzer will have access to the data which will be kept in a locked file cabinet in a locked room. To maintain confidentiality, a random code number will replace the student's name to match the pre and posttest scores. After the test scores have been appropriately matched, the coding sheet linking the students to this study will be destroyed.

Statement of Study Director This research has been approved by the Institutional Review Board for the protection of human subjects at USU. I certify that the information contained in this form is correct and that we have provided trained staff to explain the nature and purpose, possible risks and benefits associated with taking part in this study and to answer any questions that may arise.

Michael Scott	Nathan Mentzer
School Principal	Co-Principal Investigator
(877) 337-7247	(435) 797-1796

Date Created: September 17, 2007; USU IRB Approved 05/29/2007
Approval terminates 05/28/2008; Protocol Number 1838

Appendix K

CM3 Attitude Assessment Instrument Overview

The CM3 measures the degree to which an individual is motivated toward thinking.

All levels of the CM3 include the first four scales described below.
The CM3 Level II adds a fifth scale.

1. Mental Focus / Self-Regulation,
2. Learning Orientation,
3. Creative Problem Solving, and
4. Cognitive Integrity

1. Mental Focus / Self-Regulation

The person scoring high in mental focus is diligent, focused, systematic, task-oriented, organized and clear-headed. When engaged in a mental activity they tend to be focused in their attention and persistent. This person tends to agree with the statement, "It is easy for me to organize my thoughts." Those persons scoring low on this scale show a compromised ability to regulate their attention and a tendency toward disorganization and procrastination. This person tends to agree with the statement, "My trouble is I stop paying attention too soon."

2. Learning Orientation

A person scoring high in learning orientation strives to learn for learning's sake; they value the learning process as a means to accomplish mastery over a task. These individuals are eager to engage in challenging activities, they value information and evidence gathering, they recognize the importance of giving reasons to support a position, and they take an active interest and are engaged in school. A general inquisitiveness guides their interests and activities. These individuals tend to agree with the statement, "I can learn a whole lot more than I already know." Those individuals scoring low on learning orientation tend to have a narrow set of interests they are willing to explore. They may even avoid opportunities to learn and understand. These individuals will attempt to answer questions with the information they have at hand rather than seeking out new information. These individuals tend to agree with the statement, "Most academic subjects are boring."

3. Creative Problem Solving

The person scoring high in creative problem solving is intellectually curious, creative, has a preference for challenging and complicated activities, is imaginative, ingenious, and artistic. These individuals tend to agree with the statement, "If given a choice, I would pick a challenging activity over an easy one." Those individuals scoring low on creative problem solving tend to be less curious. They will choose easier activities over challenging ones. These individuals tend to disagree with the statement, "Complicated problems are fun to try to figure out."

4. Cognitive Integrity

Individuals scoring high in cognitive integrity are motivated to use their thinking skills. They are positively disposed toward truthseeking and open-mindedness.

These individuals are comfortable with challenge and complexity, they enjoy thinking about and interacting with others with potentially varying viewpoints in the search for truth or the best decision. These individuals tend to disagree with the statement, "Others have a right to their ideas, but I do not need to hear them." Those individuals scoring low on this scale express a viewpoint that is best characterized as cognitive resistance. They are hasty, indecisive, uncomfortable with challenge and change, and are likely to be anxious and close-minded. These individuals tend to agree with the statement, "I know what I think, so why should I pretend to consider choices."
5. Scholarly Rigor (*A new scale added to Level II of the CM3 in October 2006*). Scholarly Rigor is the disposition to work hard to interpret and achieve an deeper understanding of complex or abstract material. A person with a high score on this scale exhibits a strong positive disposition toward scholarly rigor would not to put off by the need to read a difficult text or to analyze complicated situations or problems. This person would tend to agree with a statement like, "I like getting the details straight." By contrast low scores on this scale point toward a significant failure to express the disposition to comprehensively seek new knowledge and examine new content in depth. These individuals tend to agree with statements like, "It takes too much time to solve some problems."

Different levels of the CM3 include different numbers of questions, with both LEVEL III and LEVEL II having 72 agree-disagree style questions and taking about 15-20 minutes to administer. Level I has 25 items and takes about the same amount of time for children to complete.

The CM3 is available on our safe, secure E-testing System. And it is supported in paper-and-pencil form by CapScore.
The CM3 is measure of mental motivation, it is not a skills test. To explore the differences between reasoning skills tests and reasoning dispositions inventories, click here or on the image of the research paper to the left.

For more information: http://www.insightassessment.com/

Appendix L

CM3 Reliability and Validity

Reliability and Validity of the CM3

Level II Correlates:

Correlations Among the CM3 Scales and Psychological Measures of Academic Motivation and Social Desirability

Correlations Among Motivation and CT Disposition Variables				
Dependent Variables	**Learning**	**Creative Problem Solving**	**Mental Focus**	**Cognitive Integrity**
Task / Mastery Goals	**.625****	**.364****	**.313****	**.193****
Performance-Approach Goals	**.230****	**.179****	**.062 (NS)**	**-.145****
Performance-Avoidance Goals	**.156****	**.099***	**-.008 (NS)**	**-.332****
Value	**.442****	**.248****	**.152****	**.170****
Self-Efficacy	**.396****	**.397****	**.351****	**.275****
Self-Handicapping	**-.109****	**-.170****	**-.278****	**-.394****
Fear of Failure	**-.206****	**-.303****	**-.294****	**-.464****

Adapted from Urdan & Giancarlo (2001). *A Comparison of Motivational and Critical Thinking Orientations Across Ethnic Groups.* In McInerney (Ed.)

Table 2.

CM3 Scale means, standard deviations, and group comparisons by ethnic group.

Scale	Filipino N = 167	Latino N = 230	Vietnamese N = 145	White N = 108
Mastery Goals	4.00[ab]	3.82[a] .69	4.05[b] .65	3.81[a] .79

	.63			
Performance-Approach Goals	3.08 .90	2.86 .89	3.14 .95	2.83 .99
Performance-Avoid Goals	2.41 .96	2.23 .84	2.39 .94	2.14 .85
Self-Efficacy	4.00 .74	3.98 .79	4.13 .71	4.17 .75
Value	3.73 .89	3.73 .88	3.68 .85	3.67 .92
Fear of Failure	2.89 [a] .63	2.82 [a] .65	2.79 [ab] .64	2.62 [b] .68
Self-Handicapping	2.37 [a] .96	2.21 [ab] .95	2.18 [ab] 1.00	1.93 [b] .73
Class Mastery Goal Structure	3.66 .71	3.54 .76	3.66 .67	3.55 .81
Class Performance Goal Structure	2.94 .70	2.78 .74	2.87 .78	2.72 .81
CM3—Learning	35.26 [bc] 7.99	33.26 [ab] 8.43	36.63 [c] 7.91	32.70 [a] 9.29
CM3—Creative Problem Solving	28.37 [ab] 7.91	26.82 [a] 8.16	29.00 [ab] 7.81	30.22 [b] 8.92
CM3—Cognitive Integrity	33.39[a] 6.94	33.49 [a] 7.74	34.40 [a] 6.19	36.52 [b] 7.22
NNAT Score	23.82[a] 6.83	21.34[b] 7.51	25.19[a] 7.20	24.44[a] 8.62

Notes: The CM3 scales were measured using a 1-4 scale and responses to the items in each scale were summed. Scores on the Naglieri test were number of correct answers out of a possible 39. All other scales measured on a 1-5 scale and the responses to the items in each scale were averaged.

Means with different superscripts indicate group differences at the $\underline{p} < .05$ level using Tukey HSD tests.

Correlations with the Marlow-Crowne Measure of Social Desirability

The correlations between the four scales of the CM3 and social desirability as measured by the Marlowe-Crowne range between -.080 and .071. These correlations were all found to be not statistically significant. This would suggest that students' scores on the CM3 are not related to the students' desire to boost their image or give a socially desirable response to question prompts. (From Urdan & Giancarlo research, unpublished findings)

Correlations Among the CM3 Scales and Academic Achievement Indicators

Correlations with GPA

All four scales of the CM3 were found to correlate significantly with GPA at the $p<.01$ level. The results in order of strength were the following: $r=.292$ for Mental Focus, $r=.220$ for Cognitive Integrity, $r=.211$ for Learning Orientation, and $r=.159$ for Creative Problem Solving. (Giancarlo, Blohm & Urdan). Even stronger correlational findings were obtained by Blohm in a study of 580 females from a private, Catholic, all-female college preparatory school in Missouri. The results in order of strength were the following: $r=.395$ for Mental Focus, $r=.375$ for Learning Orientation, $r=.315$ for Creative Problem Solving and $r=.233$ for Cognitive Integrity.

Table 3. Correlational results for CM3 scores and Stanford9 content area stanine scores.

Stanford9 Content Area Test	CM3 Scales			
	Cognitive Integrity	Creative Problem Solving	Learning Orientation	Mental Focus
Mathematics	.267**	.269**	.210**	.181**
Reading	.460**	.262**	.155**	.150**
Science	.227**	.153**	.100*	.109*
Language / Writing	.190**	--	.123*	--
Social Science	.177**	.121*	.118*	--

Note. ** These results are significant at the $p<.01$ level.

- These results are significant at the $p<.05$ level.
- (The participants for this study were 135 ninth and 349 eleventh grade students from twenty-two classrooms in a public high school in Northern California. Girls comprised 54% of the sample. The sample was ethnically diverse with 16% Latinos, 33% Asian Americans, 23% Caucasians and 17%

Filipinos forming the four major ethnic groups.) From: Giancarlo, Blohm & Urdan (Manuscript being prepared*). Development and Validation of the California Measure of Mental Motivation.*

CM3 Correlations with the NNAT: A Nonverbal Cognitive Reasoning Test

The Creative Problem Solving (r=.212), Learning Orientation (r=.107) and Cognitive Integrity (r=.261) scales of the CM3 were all found to be positively related to the Naglieri Nonverbal Abilities Test (NNAT; Naglieri, 1998). The NNAT is 38-item, culturally neutral, nonverbal measure of cognitive ability. This instrument was selected as the tool to assess cognitive reasoning because it is not dependent upon the students' ability to read, write or speak in English or other language. The NNAT uses a figural matrices question format that assesses reasoning and problem solving rather than verbal skills. The NNAT has been shown to be free of gender, race or ethnic bias, and usable with diverse student populations (Naglieri, 1997). These correlates were significant to the $p<.001$ level. (From Urdan & Giancarlo research, unpublished findings)

CM3 Correlations with the Test of Everyday Reasoning (TER; Facione, 2000).

CM3 Scale	Test of Everyday Reasoning
Mental Focus	.101*
Learning Orientation	.239**
Cognitive Integrity	.182**
Creative Problem Solving	.216**

Note: N=538; * $p<.05$, ** $p<.001$ From: Blohm's research, unpublished findings.

Constructs and descriptions of constructs measured in Urdan & Giancarlo research program.

Construct	Description
Mastery goals	Personal mastery goal orientation. "I like class work that I'll learn from even if I make a lot of mistakes."
Performance-approach goals	Personal performance-approach goal orientation. "I want to do better than other students in this class."
Performance-avoidance goals	Personal performance-avoidance goal orientation. "One of my goals is to keep others from thinking I'm not smart in English."
Self-efficacy	Perceived ability to successfully complete class work. "I can do even the hardest work in this class if I try."
Value	Valuing of academic work in English.

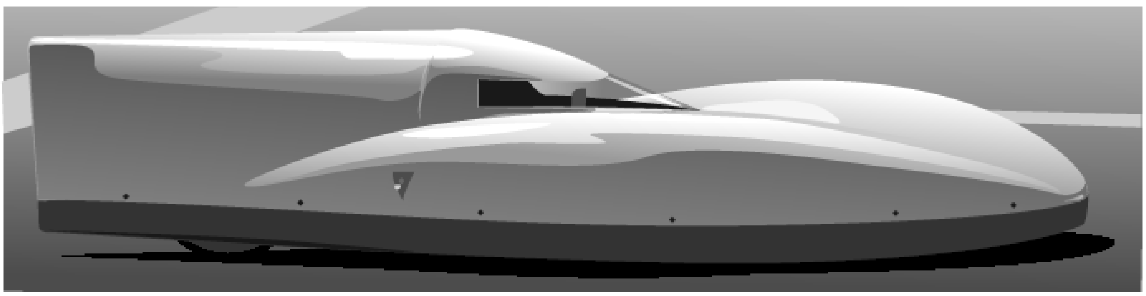
	"The information we learn about in this class is important."
Fear of failure	A generalized fear of failing. "I often avoid a task because I am afraid that I will make mistakes."
Self-Handicapping	Withdrawal of effort to avoid attributions to lack of ability. "Some students put off doing their school work until the last minute so that if they don't do well on their work they can say that is the reason. How true is this of you?"
Class Mastery Goal Structure	Perceived emphasis on mastery goals in the classroom. "In this class students really want to learn the material."
Class Performance Goal Structure	Perceived emphasis on performance goals in the classroom. "In this class, there is a lot of competition among students."
CM3—Learning	A disposition toward learning new information. "I love learning new things."
CM3—Creative Problem Solving	A disposition toward working on challenging and creative problems. "Complicated problems are fun to try to figure out."
CM3—Cognitive Integrity	A disposition away from considering various perspectives. "Thinking about other points of view is a waste of time."
NNAT Score	Sum of correct answers (out of a possible 39) on the NNAT.

Appendix M

Pilot Test Instrument for Achievement

Industry and Engineering Systems

EXAM



Directions:

- Circle the most appropriate response for each question.
- Calculators may be used.
- Work individually.

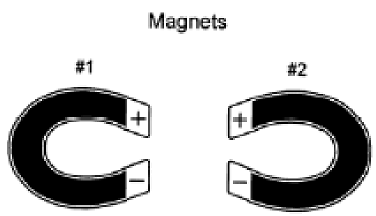
1.

The speed of an electric motor is controlled by varying the ___________ through the motor.

A) resistance
B) voltage
C) current
D) direction of the north pole

2.

The two magnets were placed near each other on a table top. Which statement about the magnetic force of these two magnets is true?



A) The two magnets will be attracted to each other.
B) The two magnets will repel each other.
C) There will be no force between the magnets.
D) The magnetic force will change the magnets.

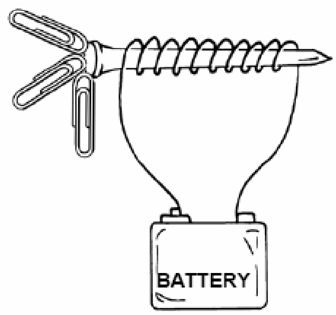
3.

A maglev train operates on the scientific principle that

A) like poles of a magnet attract.
B) unlike poles of a magnet attract.
C) a magnet can be demagnetized by electricity.
D) like poles of a magnet repel each other.

4.

Rachel made four electromagnets by winding coils of copper wire around a nail. She connected each end of the wire to a battery to form an electromagnet which she used to pick up paper clips.



In this experiment, what kind of energy is changed directly into magnetic energy?

A) Heat energy.
B) Electrical energy.
C) Chemical energy.
D) Light energy.

5.

Moving a magnet back and forth through a coil of wire will cause

A) a large electric current to flow in the magnet.
B) the magnet to become instantly too hot to hold.
C) electrons to flow in the wire coil.
D) a continuous dc voltage to be generated across the ends of the wire coil.

6.

What kind of force opposes motion and eventually brings most moving bodies to rest?

A) Strong attraction.
B) Friction.
C) Mass.
D) Inertia.

7. Which two conditions make an object the most stable?

A) A high center of mass and a narrow base.
B) A low center of mass and a large base.
C) A low center of mass and a narrow base.
D) A high center of mass and a large base.

8. Sudie took an auto trip from Columbus, Ohio, to Washington, D.C. If she spent 10 hours driving at an average speed of 40 mi/hour, the distance she traveled was:

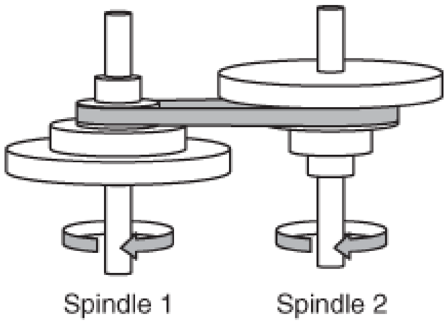
A) 1600 mi.
B) 400 mi.
C) 6.3 mi.
D) 440 mi.

9. The change in the velocity of an object divided by the change in time is the defining equation for

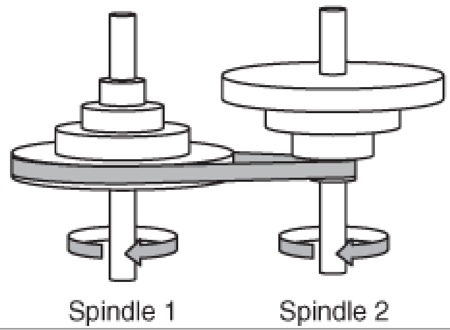
A) distance.
B) speed.
C) acceleration.
D) displacement.

10.	Which configuration of pulleys and belts shown below will result in the fastest rotation of Spindle 2?

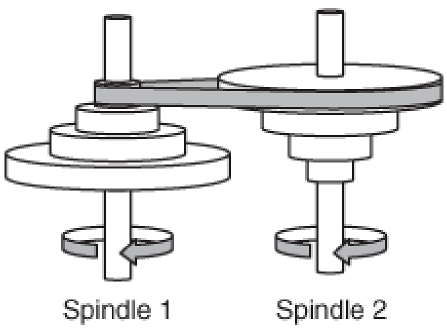
A)



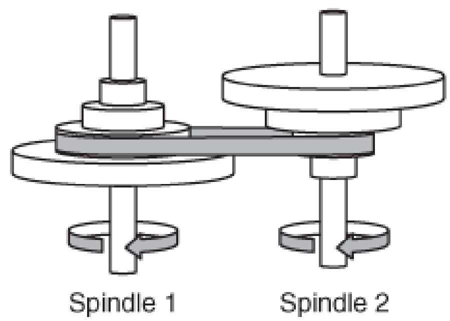
B)



C)



D)



11.	The total distance around the outside perimeter of a circle is properly called the

A) circumference.
B) diameter.
C) radius.
D) degree.

12.	Motion combines the concepts of position change (length) and time. Which of the following combinations of units is used to describe the velocity of a moving object?

A) length x time
B) length/time
C) length/time2
D) time/length

13. The force exerted on a cart is constant. On a frictionless surface, if the cart's mass is increased, the acceleration will

A) increase only.
B) decrease only.
C) increase, then decrease.
D) decrease, then increase.

14. The product of mass and velocity of a moving object is defined as its

A) linear momentum.
B) normal force.
C) net force.
D) impulse.

15. If it starts motion, stops motion, or changes motion, it must be

A) drag.
B) inertia.
C) friction.
D) force.

16. Torque is

A) just another word for weight.
B) a twisting effect caused by forces that can produce a rotational motion.
C) the force that makes a car follow a curved path.
D) the force that keeps satellites in orbit.

17.

Torque is defined as:

A) The product of the length, measured in pounds, and the force, measured in feet.
B) The product of the force applied and the length of the lever arm.
C) The product of the force, measured in pounds, and the length, measured in newtons.
D) The speed at which a body rotates.

18.

A torque wrench has a lever arm that's 18 inches long. A force of 20 pounds is applied to the end of the wrench to tighten a bolt. The torque applied is

A) 40 lb*ft
B) 30 lb*ft
C) 360 lb*ft
D) 100 lb*ft

19.

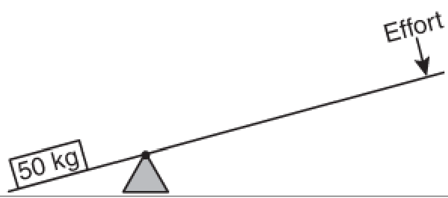
Drag forces on a car moving through air can be reduced by:

A) Increasing the speed of the car.
B) Making the front end of the car more blunt.
C) Streamlining.
D) Letting air out of the tires.

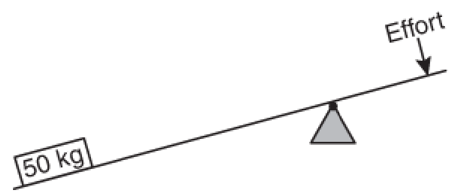
20.

Which lever requires the least effort to lift the load?

A)

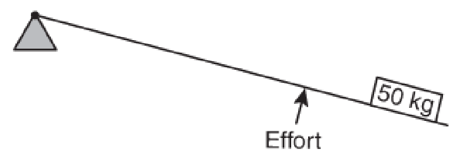


B)



C)

D)



21.

When the air is released from a balloon, the air moves in one direction, and the balloon moves in another direction. Which statement does this situation best illustrate?

A) What goes up must come down.
B) For every action there is an equal and opposite reaction.
C) The shape and size of an object affect air resistance.
D) The acceleration due to Earth’s gravity is 9.8 m/s 2.

22.

Although a battery outputs electricity, it starts with

A) electromagnetic energy.
B) thermal energy.
C) mechanical energy.
D) chemical energy.

23.

Unlike an insulator, a conductor

A) changes direct current into alternating current.
B) allows electron flow in one direction only.
C) blocks or partially blocks the flow of electrons.
D) allows electrons to flow easily.

24.

Which material is not a good conductor?

A) Gold.
B) Silver.
C) Plastic.
D) Copper.

25.

A generator converts mechanical energy, such as that of a spinning turbine, into

A) nuclear energy.
B) chemical energy.
C) electrical energy.
D) heat energy.

26.

Resistance

A) is measured in amperes.
B) is the opposition to the flow of electric current.
C) is the driving force that moves electrons in conductors.
D) is not affected by temperature changes.

27.

A photovoltaic cell is a device that

A) captures and stores the sun's heat.
B) outputs mechanical energy.
C) transforms sun rays into electrical current.
D) depends on fossil fuels to do its work.

28.

A complete pathway through which electrons can flow is a(n)

A) static charge.
B) circuit.
C) insulator.
D) magnet.

29.	What devices will protect a circuit from excessive current flow?

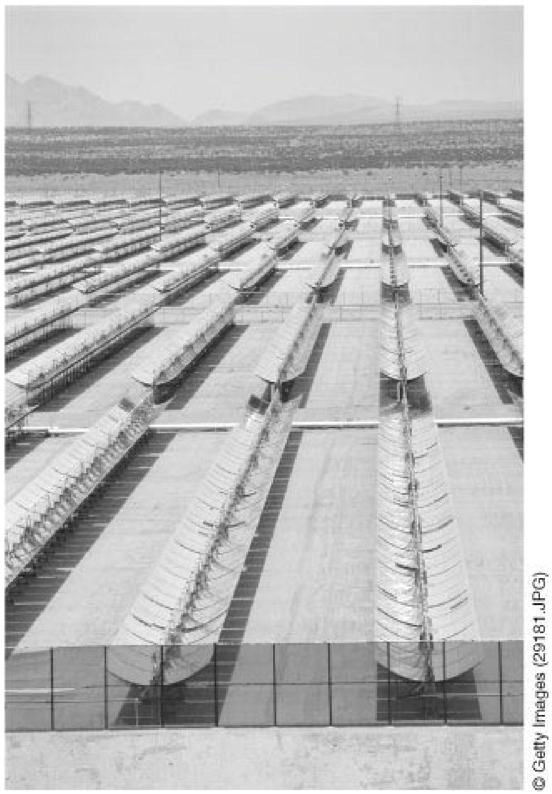
A) Switches and diodes.
B) Resistors.
C) Circuit breakers and fuses.
D) Surge suppressors.

30.	What happens to lights in series if one goes out?

A) They all go out.
B) They flicker.
C) Every other one goes out.
D) They stay lit.

31.

This picture shows a small section of a solar power plant. Which of these decreases the energy production at such power plants?



A) Cloudy skies.
B) Ozone in the air.
C) Hot weather.
D) Low humidity.

32.

When the temperature of an automobile tire increases as you drive on a long trip, the pressure in the tire should

A) remain the same, as long as the volume doesn't change.
B) increase, as long as the volume doesn't change.
C) decrease, as long as the volume doesn't change.
D) There is no way to predict how temperature affects tire pressure.

33\.

Energy is defined as

A) power.
B) motion.
C) the effort required to perform work.
D) the ability of an object to produce change in the environment or itself.

34\.

The ___________ of a machine is defined as the ratio of output work to input work.

A) reliability
B) IMA
C) mechanical advantage
D) efficiency

35\.

How can power be calculated?

A) Multiply the force times the parallel distance.
B) Multiply the mass times g times the height.
C) Calculate the change in total energy of the system.
D) Divide the work done by the time it takes.

36\.

An object that is at rest will have zero velocity. This means that it will also have zero

A) mass.
B) kinetic energy.
C) potential energy.
D) horsepower.

37. ___________ is energy stored for later use.

A) Potential energy
B) Kinetic energy
C) Conservation of energy

38. ___________ is energy of motion.

A) Potential energy
B) Kinetic energy
C) Conservation of energy

39. ___________ often changes when a body’s shape changes.

A) Potential energy
B) Kinetic energy
C) Conservation of energy

40. ___________ is present in a stretched spring that’s not moving.

A) Potential energy
B) Kinetic energy
C) Conservation of energy

41. ___________ implies that the total energy of a system is constant, if all forms of energy are considered.

A) Potential energy
B) Kinetic energy
C) Conservation of energy

42.

___________ increases when a body’s speed increases.

A) Potential energy
B) Kinetic energy
C) Conservation of energy

43.

The magnitude of an object's gravitational potential energy can be calculated by multiplying

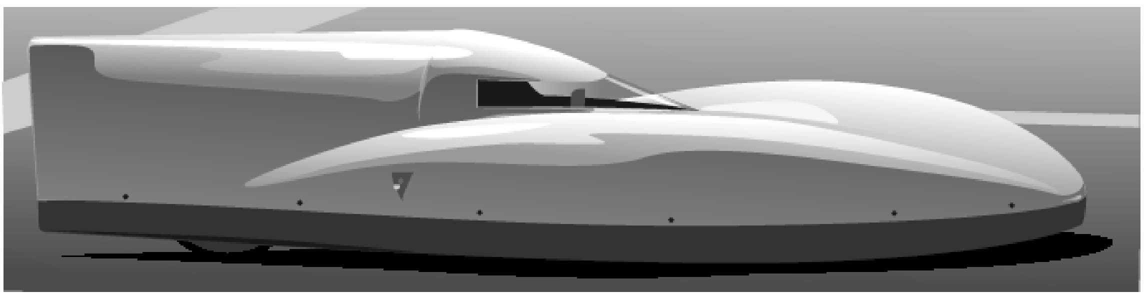
A) mass times height.
B) weight times height.
C) 1/2 the mass times the velocity squared.
D) mass times velocity.

Appendix N

Achievement Test A

Industry and Engineering Systems

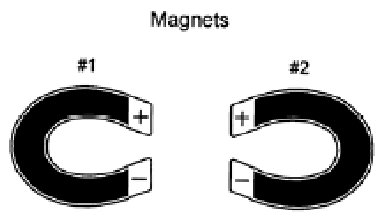
EXAM



Directions:

- Circle the most appropriate response for each question.
- Calculators may be used.
- Work individually.

1. The two magnets were placed near each other on a table top. Which statement about the magnetic force of these two magnets is true?



A) The two magnets will be attracted to each other.

B) The two magnets will repel each other.

C) There will be no force between the magnets.

D) The magnetic force will change the magnets.

2. Which two conditions make an object the ***most*** stable?

A) A high center of mass and a narrow base.

B) A low center of mass and a large base.

C) A low center of mass and a narrow base.

D) A high center of mass and a large base.

3. If it starts motion, stops motion, or changes motion, it must be

A) drag.

B) inertia.

C) friction.

D) force.

4. Unlike an insulator, a conductor

A) changes direct current into alternating current.

B) allows electron flow in one direction only.

C) blocks or partially blocks the flow of electrons.

D) allows electrons to flow easily.

5. When the temperature of an automobile tire increases as you drive on a long trip, the pressure in the tire should

A) remain the same, as long as the volume doesn't change.

B) increase, as long as the volume doesn't change.

C) decrease, as long as the volume doesn't change.

D) There is no way to predict how temperature affects tire pressure.

6. How can power be calculated?

A) Multiply the force times the parallel distance.

B) Multiply the mass times gravity times the height.

C) Calculate the change in total energy of the system.

D) Divide the work done by the time it takes.

7. A maglev train operates on the scientific principle that

A) like poles of a magnet attract.

B) unlike poles of a magnet attract.

C) a magnet can be demagnetized by electricity.

D) like poles of a magnet repel each other.

8. Sudie took an auto trip from Eugene to Sacramento, California. If she spent 10 hours driving at an average speed of 40 mi/hour, the distance she traveled was:

A) 1600 mi.

B) 400 mi.

C) 6.3 mi.

D) 440 mi.

9. Torque is

A) just another word for weight.

B) a twisting effect caused by forces that can produce a rotational motion.

C) the force that makes a car follow a curved path.

D) the force that keeps satellites in orbit.

10. Which material is **not** a good conductor?

A) Copper.

B) Gold.

C) Silver.

D) Plastic.

11. Which of the following describes the mechanical energy of a cart at rest at the top of a steep hill?

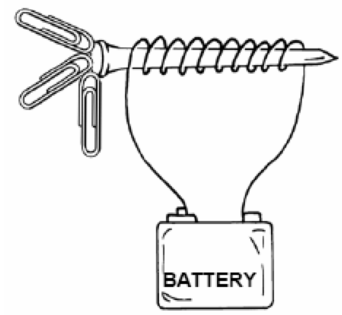
A) The cart has no mechanical energy.

B) The cart's mechanical energy is all kinetic.

C) The cart's mechanical energy is all potential.

D) The cart's mechanical energy is half potential and half kinetic.

12. Rachel made four electromagnets by winding coils of copper wire around a nail. She connected each end of the wire to a battery to form an electromagnet which she used to pick up paper clips.



In this experiment, what kind of energy is changed directly into magnetic energy?

A) Heat energy.

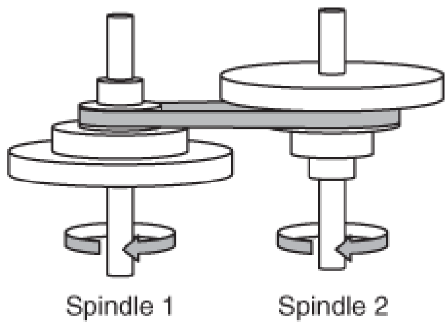
B) Electrical energy.

C) Chemical energy.

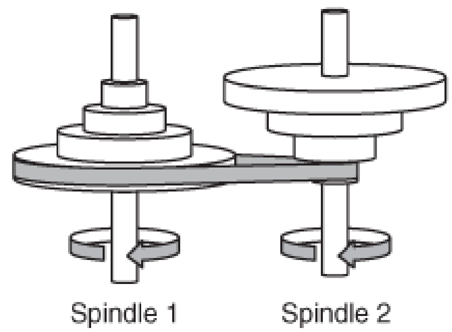
D) Light energy.

13. Which configuration of pulleys and belts shown below will result in the ***fastest*** rotation of Spindle 2?

A)



B)



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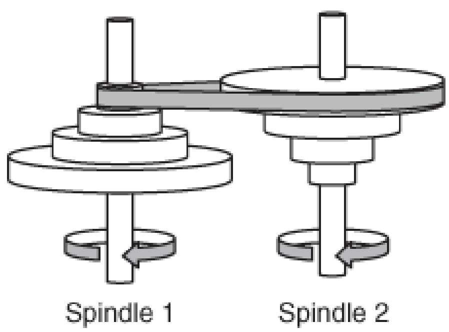
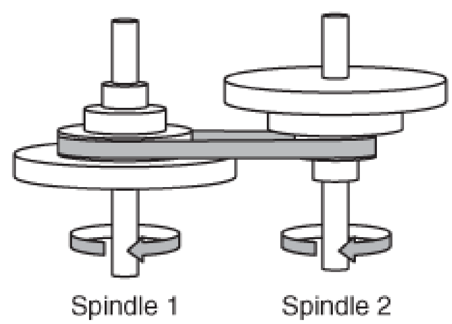


D)



14. A torque wrench has a lever arm that's 18 inches long. A force of 20 pounds is applied to the end of the wrench to tighten a bolt. The torque applied is

A) 40 ft·lb

B) 30 ft·lb

C) 360 ft·lb

D) 100 ft·lb

15. A generator converts mechanical energy, such as that of a spinning turbine, into

A) nuclear energy.
B) chemical energy.
C) electrical energy.
D) heat energy.

16. Which type of energy is defined as the energy of motion?

A) Kinetic energy.
B) Total energy.
C) Energy that can do work.
D) Potential energy.

17. Moving a magnet back and forth through a coil of wire will cause

A) a large electric current to flow in the magnet.
B) the magnet to become instantly too hot to hold.
C) electrons to flow in the wire coil.
D) a continuous dc voltage to be generated across the ends of the wire coil.

18. The total distance around the outside perimeter of a circle is properly called the

A) circumference.
B) diameter.
C) radius.
D) degree.

19. Drag forces on a car moving through air can be ***reduced*** by:

A) Increasing the speed of the car.

B) Making the front end of the car more blunt.

C) Streamlining.

D) Letting air out of the tires.

20. Resistance

A) is measured in amperes.

B) is the opposition to the flow of electric current.

C) is the driving force that moves electrons in conductors.

D) is not affected by temperature changes.

21. __________ is present in a stretched spring that's not moving.

A) Potential energy

B) Kinetic energy

C) Conservation of energy

22. Motion combines the concepts of position change (length) and time. Which of the following combinations of units is used to describe the velocity of a moving object?

A) length x time

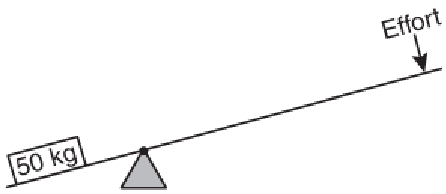
B) length/time

C) length/time^2

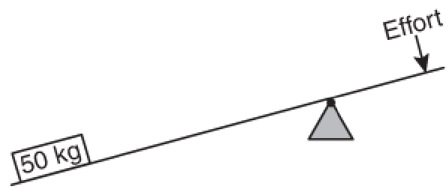
D) time/length

23. Which lever requires the least effort to lift the load?

A)

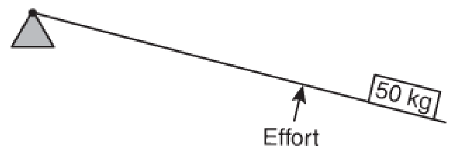


B)



C)

D)



24. A photovoltaic cell is a device that

- **A)** captures and stores the sun's heat.
- **B)** outputs mechanical energy.
- **C)** transforms sun rays into electrical current.
- **D)** depends on fossil fuels to do its work.

25. __________ implies that the total energy of a system is constant, if all forms of energy are considered.

- **A)** Potential energy
- **B)** Kinetic energy
- **C)** Conservation of energy

26. Multiplying mass and velocity of a moving object is defined as its

A) momentum.

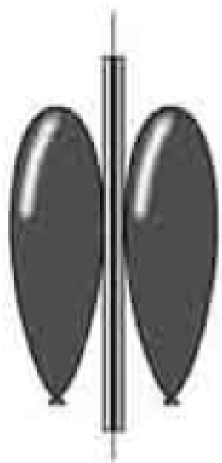
B) normal force.

C) net force.

D) impulse.

27. A string is placed through a straw and attached to the floor and ceiling. Two balloons are used to make a balloon rocket. Which picture shows the best way to attach the balloons to make the rocket go as high as possible?

A)



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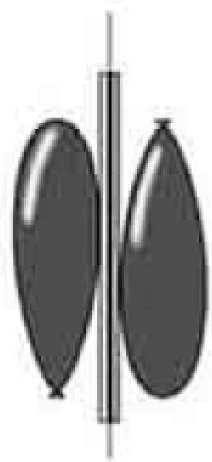
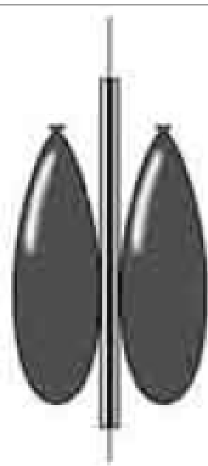
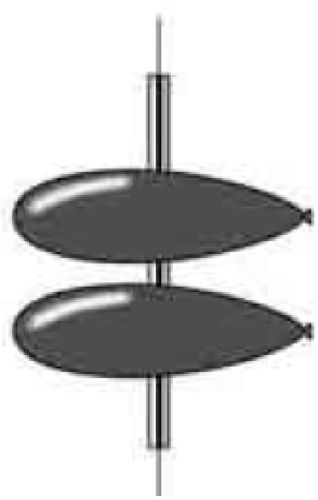


C)



D)



28. What happens to lights in series if one goes out?

A) They all go out.

B) They flicker.

C) Every other one goes out.

D) They stay lit.

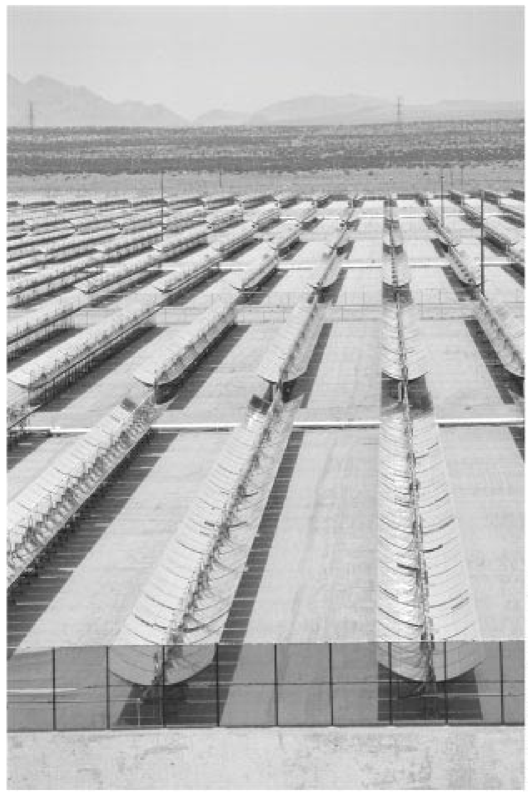
29. __________ increases when a body's speed increases.

A) Potential energy

B) Kinetic energy

C) Conservation of energy

30. This picture shows a small section of a solar power plant. Which of these decreases the energy production at such power plants?



© Getty Images (29181.JPG)

A) Cloudy skies.

B) Ozone in the air.

C) Hot weather.

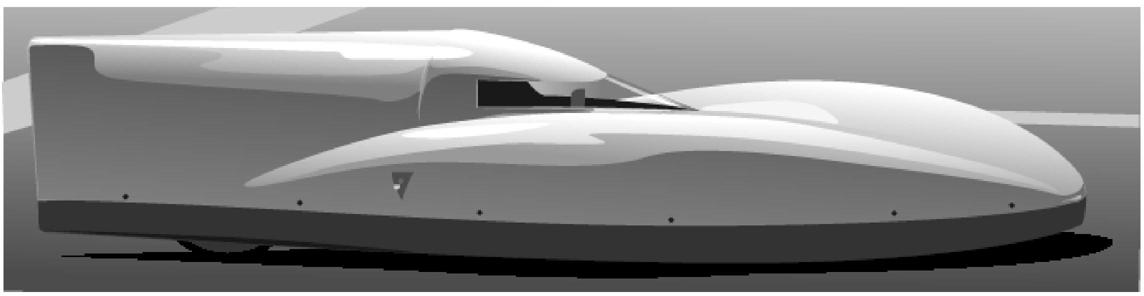
D) Low humidity.

Appendix O

Achievement Test B

Industry and Engineering Systems

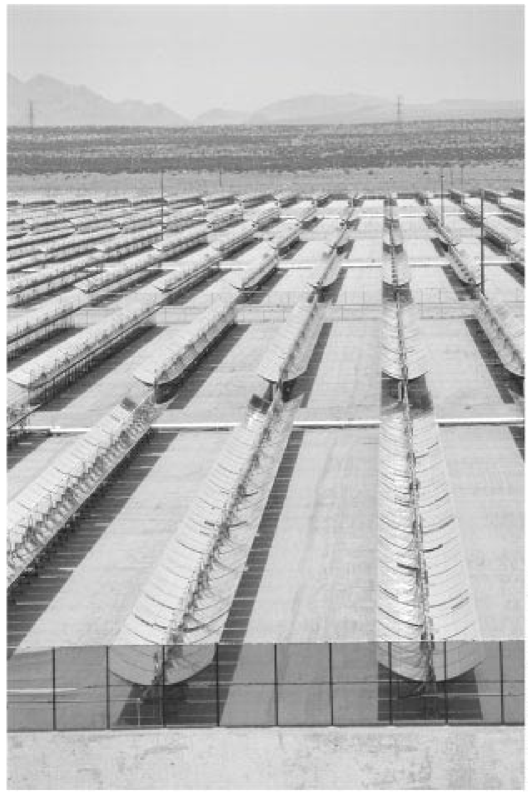
EXAM



Directions:

- Circle the most appropriate response for each question.
- Calculators may be used.
- Work individually.

1. This picture shows a small section of a solar power plant. Which of these decreases the energy production at such power plants?



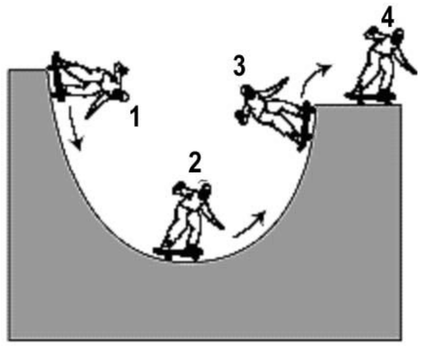
A) Low humidity.

B) Cloudy skies.

C) Ozone in the air.

D) Hot weather.

2. A skateboarder travels from location 1 to location 4 as shown below.



At which location does the skateboarder have the **most** kinetic energy and the **least** potential energy?

A) 1

B) 2

C) 3

D) 4

3. When the air is released from a balloon, the air moves in one direction, and the balloon moves in another direction. Which statement does this situation best illustrate?

A) What goes up must come down.

B) For every action there is an equal and opposite reaction.

C) The shape and size of an object affect air resistance.

D) The acceleration due to Earth's gravity is 9.8 m/s^2.

4. The momentum of a body can be calculated by multiplying its mass by the

A) time during which the mass moves.

B) acceleration of the mass.

C) distance the mass moves.

D) velocity of the mass.

5. Which of the following situations violates the law of conservation of energy?

A) A ball dropped from the top of a building increase in speed until it hits the ground.
B) A block sliding freely on level ice increases in speed until it hits a wall.
C) A child playing on a swing moves fastest at the bottom of the swing's path.
D) The height a ball bounces decreases with each bounce.

6. Which of the following could be used to convert light energy to electrical energy?

A) a windmill.

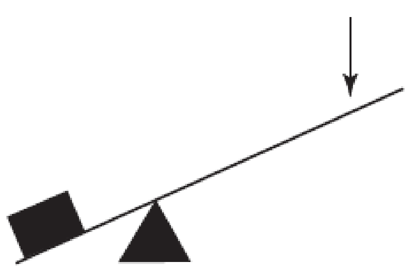
B) a chemical storage battery.

C) a solar cell.

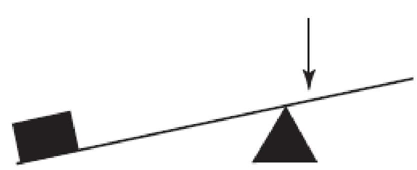
D) rotating coils in a magnetic field.

7. Which lever arrangement required the least effort force to raise a 50 pound resistance?

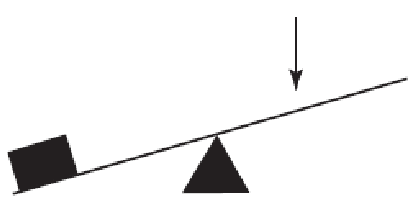
A)



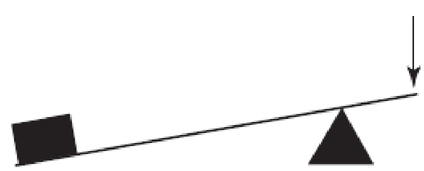
B)



C)



D)



8. How is velocity calculated?

- **A)** By dividing revolutions by time
- **B)** By dividing torque by time
- **C)** By dividing distance by time
- **D)** By dividing revolutions by torque

9. A stretched, stationary auto brake spring is an example of

- **A)** Potential energy.
- **B)** Kinetic energy.
- **C)** Conservation of energy.

10. A student designs a circuit that has a battery, a resistor, and a light bulb connected in series. Which changes could be made to the circuit so that each would contribute to a ***brighter*** glow from the light bulb.

- **A)** decrease the voltage and decrease the resistance.
- **B)** decrease the voltage and increase the resistance.
- **C)** increase the voltage and decrease the resistance.
- **D)** increase the voltage and increase the resistance.

11. A force that slows down or stops the motion of a bicycle is

- **A)** sound.
- **B)** heat.
- **C)** friction.
- **D)** electricity.

12. The total distance around the outside perimeter of a circle is properly called the

A) diameter.

B) degree.

C) radius.

D) circumference.

13. Which of the following actions would ***decrease*** the strength of an electromagnet?

A) Removing turns from the wire coil.

B) Increasing the amount of current used.

C) Inserting a core of iron within the coil.

D) Adding more turns to the wire coil.

14. __________ is energy of motion.

A) Potential energy

B) Kinetic energy

C) Conservation of energy

15. What converts chemical energy into electrical energy?

A) Battery.

B) Transformer.

C) Alternator.

D) DC generator.

16. If a bolt must be tightened to a specification in inch-pounds (in.-lbs.) or foot-pounds (ft.-lbs.), what should you use?

A) A strap wrench.

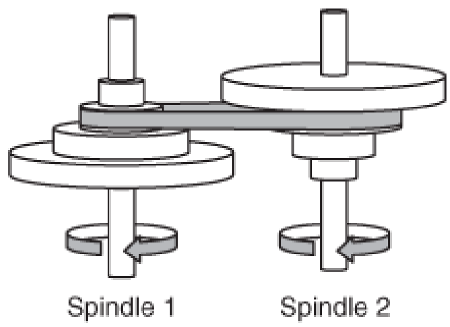
B) A feeler gauge.

C) A micrometer.

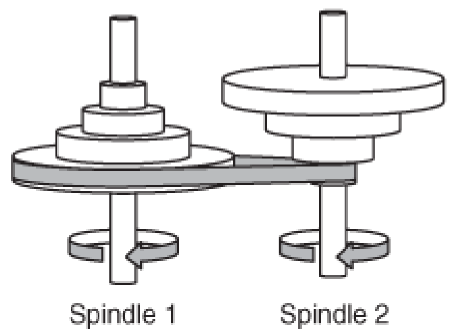
D) A torque wrench.

17. Which configuration of pulleys and belts shown below will result in the ***slowest*** rotation of Spindle 2?

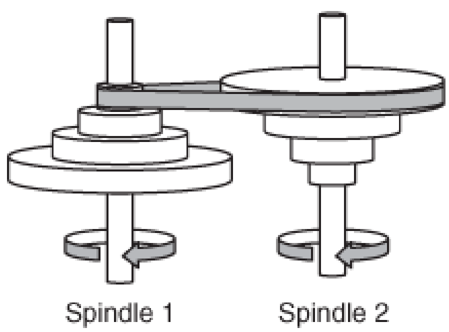
A)



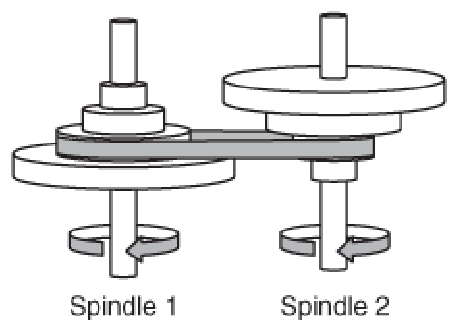
B)



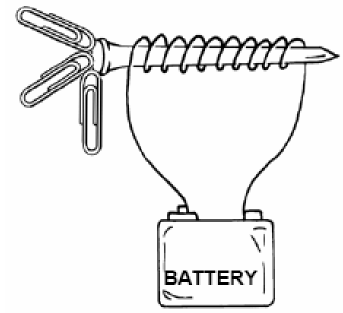
C)



D)



18. Conrad made four electromagnets by winding coils of copper wire around a nail. He connected each end of the wire to a battery to form an electromagnet which he used to pick up paper clips.



In this experiment, what kind of energy is changed directly into magnetic energy?

A) Light energy.

B) Heat energy.

C) Electrical energy.

D) Chemical energy.

19. Water stored behind a dam is an example of:

A) Potential energy.

B) Kinetic energy.

C) Conservation of energy.

20. Which material is **not** a good conductor?

A) Gold.

B) Silver.

C) Plastic.

D) Copper.

21. A force that applies twisting pressure is

A) conductivity.
B) torsion.
C) shear.
D) resistance.

22. Sarah traveled by automobile from Eugene to Portland, a distance of 120 miles, at an average speed of 60 mi/h. The time required was

A) 0.50 hours.
B) 5000 hours.
C) 2.5 hours.
D) 2.0 hours.

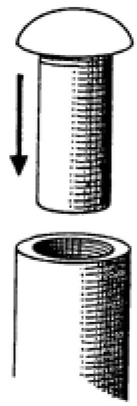
23. A vehicle that gets power from the repelling and attracting forces in magnetism is the

A) fighter jet.
B) diesel truck.
C) maglev train.
D) oil tanker.

24. Power

A) is force divided by time.
B) is work divided by time.
C) is work times time.
D) has the same units as energy.

25. You need to put a metal rod into a hole in a metal cylinder. It is too tight. Which would be the best strategy to make the rod fit?



A) Heat the rod and cylinder.

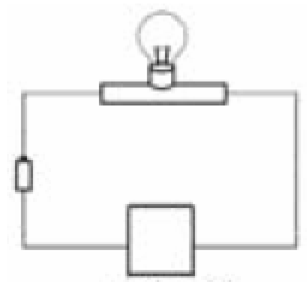
B) Cool the rod and cylinder.

C) Heat the rod and cool the cylinder

D) Cool the rod and heat the cylinder

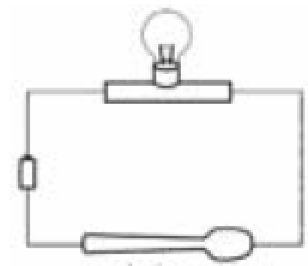
26. The following diagrams show a battery and a bulb connect by wires to various materials. Which of the bulbs will light?

Bulb 1



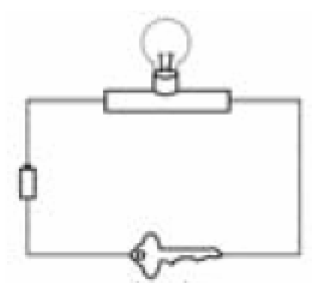
Aluminum foil

Bulb 2



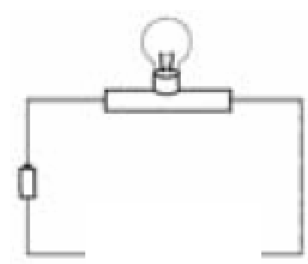
Plastic spoon

Bulb 3



Brass key

Bulb 4



Air

A) Bulb 1 only.

B) Bulb 2 and 3 only.

C) Bulb 1 and 3 only.

D) Bulb 1, 3, and 4 only

27. If it starts motion, stops motion, or changes motion, it must be

A) inertia.

B) drag.

C) force.

D) friction.

28. Which two conditions make an object the ***least*** stable?

A) A low center of mass and a large base.

B) A high center of mass and a narrow base.

C) A high center of mass and a large base.

D) A low center of mass and a narrow base.

29. Electrical elements that are connected in a circuit so that the same current must pass through each one in turn are said to be connected in

A) resonance.

B) dc.

C) parallel.

D) series.

30. The north pole of a stationary magnet will be attracted to

A) another north magnetic pole.

B) a south magnetic pole.

C) a negative electrostatic charge.

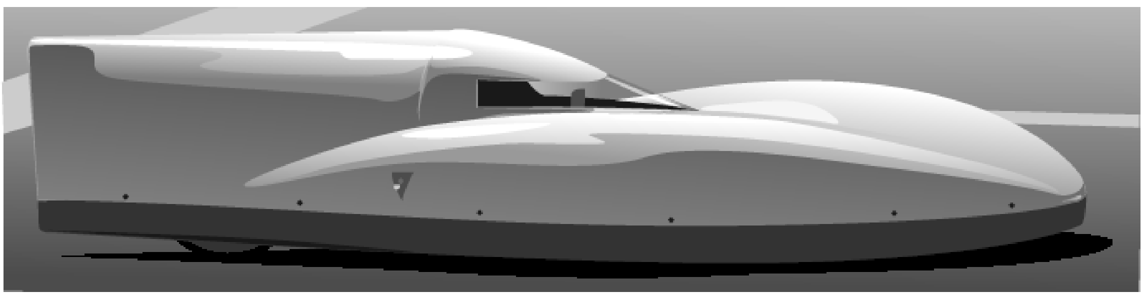
D) a positive electrostatic charge.

Appendix P

Achievement Test C

Industry and Engineering Systems

EXAM



Directions:

- Circle the most appropriate response for each question.
- Calculators may be used.
- Work individually.

1. Which two conditions make a car the ***most*** stable?

A) A low center of mass and a narrow wheelbase.

B) A high center of mass and a wide wheelbase.

C) A high center of mass and a narrow wheelbase.

D) A low center of mass and a wide wheelbase.

2. Copper wire and solder are each classified as:

A) Resistors.

B) Semiconductors.

C) Insulators.

D) Conductors.

3. Any massive object that is moving will always have

A) potential energy.

B) kinetic energy.

C) an unbalanced force acting on it.

D) angular momentum.

4. An airplane takes off from Eugene for the 608 mile trip to Los Angeles. The plane lands two hours later. Which of the following **best** describes the average speed of the airplane's flight?

A) 201 mph

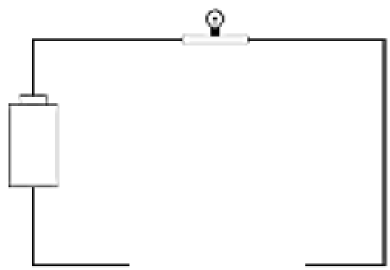
B) 304 mph

C) 608 mph

D) 1216 mph

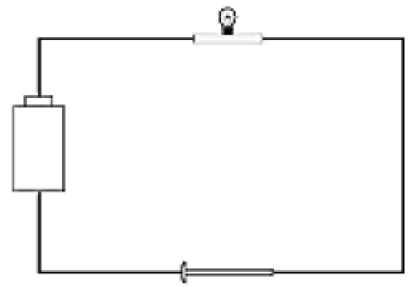
5. The following diagrams show a flashlight battery and a bulb connected by wires to various substances. Which of the bulbs will light?

Bulb 1



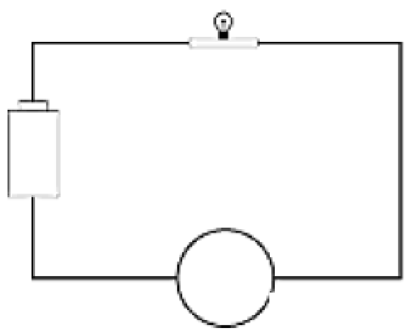
Air

Bulb 2



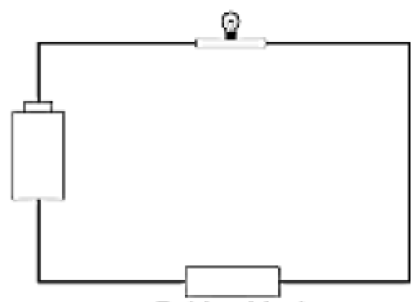
Steel Nail

Bulb 3



Copper Coin

Bulb 4



Rubber Block

A) Bulb 1 and 2 only

B) Bulb 2 and 3 only

C) Bulb 3 and 4 only

D) Bulb 1, 2, and 3 only

6. When dropped from the same height, why does a flat sheet of paper fall more slowly than the same sheet when it is tightly crumpled into a ball?

A) The sheet of paper has less mass when it is flat than it does when it is crumpled.
B) The sheet of paper weighs less when it is flat than it does when it is crumpled.
C) The force of gravity has a greater effect on the crumpled paper than it does on the flat paper.
D) The flat sheet of paper has greater surface area and encounters more air resistance than when it is crumpled.

7. A torque wrench has a lever arm that's 12 inches long. A force of 20 pounds is applied to the end of the wrench to tighten a bolt. The torque applied is

A) 12 ft·lb

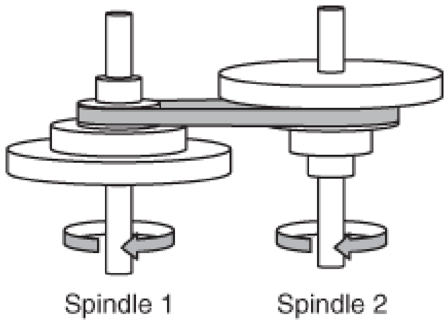
B) 30 ft·lb

C) 240 ft·lb

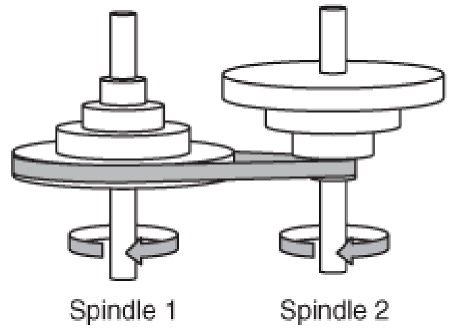
D) 20 ft·lb

8. Which configuration of pulleys and belts shown below will result in the ***greatest*** torque at Spindle 2?

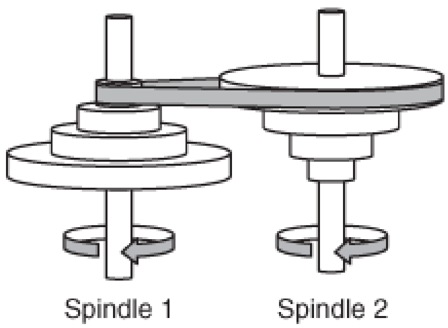
A)



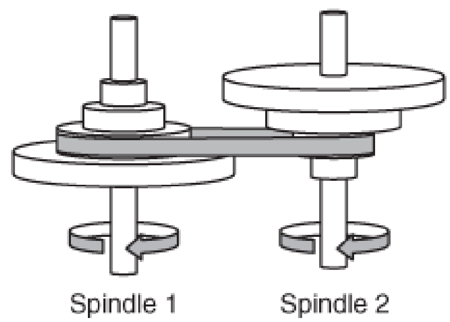
B)



C)



D)



9. An object is placed on a table. A magnet is slowly moved toward it. The object moves away from the magnet. The object is most likely

A) another magnet.

B) a piece of glass.

C) a copper coin.

D) an iron nail.

10. Household appliances convert electricity into one or more different forms of energy. An electric fan can best be described as converting electricity into

A) heat energy only

B) heat energy and sound energy only

C) heat energy, sound energy, and mechanical energy only

D) heat energy, sound energy, mechanical energy, and chemical energy only

11. A student designs a circuit that has a battery, a resistor, and a light bulb connected in series. Which changes could be made to the circuit so that each would contribute to a ***less bright*** glow from the light bulb?

A) decrease the voltage and increase the resistance.

B) decrease the voltage and decrease the resistance.

C) increase the voltage and increase the resistance.

D) increase the voltage and decrease the resistance.

12. If it starts motion, stops motion, or changes motion, it must be

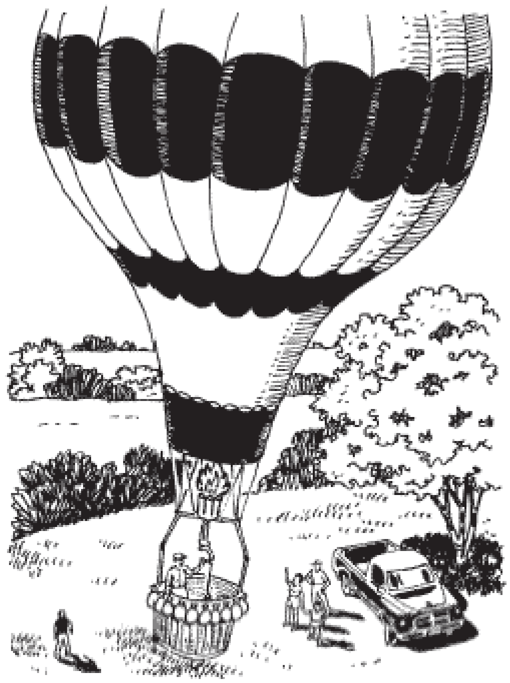
A) force.

B) friction.

C) inertia.

D) drag.

13. The illustration below shows a hot-air balloon. The pilot can change the altitude of the hot-air balloon by changing the temperature of the gas inside the balloon. When the gas is heated, the balloon rises.



Which of the following **best** explains this phenomenon?

A) Heating the gas reduces its pressure.

B) Heating the gas decreases its density.

C) Heating the gas decreases its molecular motion.

D) Heating the gas reduces the frequency of the gas molecules' collisions.

14. A maglev train operates on the scientific principle that

A) a magnet can be demagnetized by electricity.

B) like poles of a magnet repel each other.

C) like poles of a magnet attract.

D) unlike poles of a magnet attract.

15. A flywheel that’s spinning is an example of

A) Potential energy.

B) Kinetic energy.

C) Conservation of energy.

16. Which of the following actions would ***decrease*** the strength of an electromagnet?

A) Increasing the amount of current used.

B) Inserting a core of iron within the coil.

C) Adding more turns to the wire coil.

D) Removing turns from the wire coil.

17. A photovoltaic cell is a device that

A) outputs mechanical energy.

B) transforms sun rays into electrical current.

C) depends on fossil fuels to do its work.

D) captures and stores the sun's heat.

18. In order to determine the speed of an object, what measurements must be made?

A) Distance and direction.

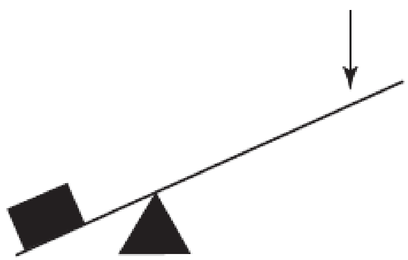
B) Distance and mass.

C) Time, distance, and volume.

D) Distance and time.

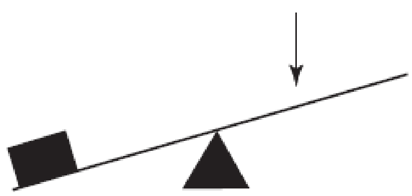
19. Which lever requires the least effort to lift the load?

A)



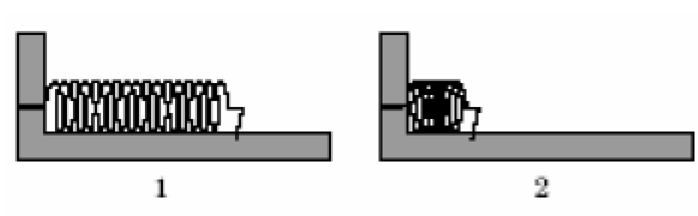
B)

C)



D)

20. Spring 1 and Spring 2 were the same. Then, Spring 1 was pushed together a little and clamped in place. Spring 2 was pushed together a lot and clamped.



Which spring has more stored energy?

A) Spring 1.

B) Spring 2.

C) Both springs have the same energy.

D) You cannot tell unless you know what the springs are made of.

21. What is the definition of power?

A) The rate at which work is done

B) The ability to do work

C) Work

D) Effort

22. When the air is released from a balloon, the air moves in one direction, and the balloon moves in another direction. Which statement does this situation best illustrate?

A) For every action there is an equal and opposite reaction.

B) What goes up must come down.

C) The acceleration due to Earth's gravity is 9.8 m/s^2.

D) The shape and size of an object affect air resistance.

23. A change in momentum of an object means that

A) the weight of the object is also changing.

B) the inertia of the object is changing.

C) the velocity of the object must also be changing.

D) the object must immediately come to a complete stop and remain at rest.

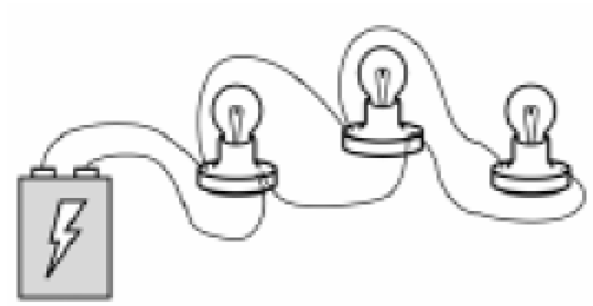
24. _________ is energy stored for later use.

A) Potential energy

B) Kinetic energy

C) Conservation of energy

25. A student connects three identical light bulbs in parallel to a dry cell as shown below. What happens when the student removes one of the light bulbs from its socket?



A) All the light bulbs go out.

B) The other light bulbs remain on and will be equally bright.

C) The other light bulbs remain on, one less bright and the other the same brightness as before.

D) The other light bulbs remain on, one brighter and the other less bright than before.

26. A solar heater uses energy from the sun to heat water. The heater's panel is painted black to -

A) improve emission of infrared radiation.

B) reduce the heat loss by convection currents.

C) improve absorption of infrared radiation.

D) reduce the heater's conducting properties.

27. Torque is a term for which of the following?

A) Effort in linear mechanical power.

B) Rate in rotary mechanical power.

C) Effort in rotary mechanical power.

D) Rate in linear mechanical power.

28. What produces electrical energy using mechanical energy?

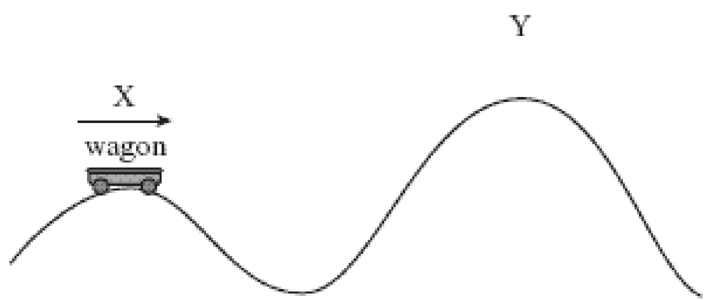
A) Battery.

B) Transformer.

C) Alternator.

D) Electrolyte.

29. The figure below shows a wagon that moves from point X to point Y.



Which of the following **best** describes the wagon's change in energy as it coasts from point X to point Y?

A) The wagon has the same kinetic energy at point Y and at point X.

B) The wagon has more kinetic energy at point Y than at point X.

C) The wagon has the same gravitational potential energy at point Y and at point X.

D) The wagon has more gravitational potential energy at point Y than at point X.

30. The total distance around the outside perimeter of a circle is properly called the

A) radius.

B) diameter.

C) circumference.

D) degree.

Appendix Q

Achievement Test Skill Specification

Table Q-1

Achievement Instrument Specifications

	Test version		
Skill area	A	B	C
Magnetism and electric motors	1[o]	30[o]	9[o]
	7[o]	23[m]	14[r]
	12[o]	18[r]	10[m]
	17[o]	13[o]	16[r]
Motion	2[o]	28[m]	1[m]
	8[m]	22[m]	4[m]
	13[o]	17[m]	8[m]
	18[o]	12[r]	30[r]
	22[o]	8[o]	18[o]
	26[m]	4[o]	23[o]
Force	3[o]	27[r]	12[r]
	9[o]	21[o]	27[o]
	14[o]	16[o]	7[m]
	19[o]	11[o]	6[o]
	23[o]	7[o]	19[m]
	27[o]	3[o]	22[r]
Electricity	4[o]	26[o]	5[o]
	10[o]	20[r]	2[o]
	15[o]	15[o]	28[o]
	20[o]	10[o]	11[m]
	24[o]	6[o]	17[r]
	28[o]	29[o]	25[o]
	30[o]	1[r]	26[o]
Air pressure	5[o]	25[o]	13[o]
Energy	6[o]	24[o]	21[o]
	11[o]	19[o]	24[o]
	16[o]	14[o]	15[o]
	21[o]	9[o]	20[o]
	25[o]	5[o]	29[o]
	29[o]	2[o]	3[o]

[o] Original question
[m] Modified question
[r] Repeated Question

Appendix R

CM3 Sample Reasoning Motivation and Disposition Items

CM3 Sample Reasoning Motivation and Disposition Items

Consider the following 25 statements about beliefs, opinions, values, and preferences. Decide whether you agree or disagree with each one. Remember that since you are being asked about your own beliefs, opinions, values, and preferences, there really is no "right" or "wrong" response. The answer is whatever you say it is for you.

You can indicate the extent of your affirmation or rejection of each statement by giving each one a point value where as follows.

6 = Agree Strongly
5 = Agree
4 = Agree Marginally
3 = Disagree Marginally
2 = Disagree
1 = Disagree Strongly

1. I hate talk-radio hosts because they shout out their views without really listening to the other side.

2. I won't let what scientists might say weaken my core beliefs.

3. I prefer jobs where the supervisor says exactly what to do, and exactly when and how to do it.

4. It's important to me to figure out what people really mean by what they say.

5. Don't kid yourself, changing your mind is a sign of weakness.

6. I always do better in jobs where I'm expected to think things out for myself.

7. If I wanted to persuade someone of something, I wouldn't stop talking until the person gave up.

8. My friends expect me to be able to figure out a smart way to deal with all kinds of problems.

9. For me the best way to make decisions is to go with my gut feelings.

10. I hold off making decisions until I've thought through my options.

11. No matter how complex the problem, you can bet there's a really simple solution.

12. Rather than relying on someone else's notes, I prefer to read the material myself.

13. I enjoy challenging myself mentally.

14. I try to see the merit in another's opinion, even if I reject it later.

15. I don't want to be on a jury because it means deciding something beyond a reasonable doubt.

16. People say I change my mind too easily.
17. If my belief is truly sincere, evidence to the contrary is irrelevant.

18. I'd love to learn all kinds of new things just for the fun of it.

19. Even if a problem is tougher than I expected, I'll keep working on it.

20. I hate it when teachers want to discuss test questions instead of just giving the answers.

21. I can spend days and days thinking about my problems.

22. Making intelligent decisions is more important than winning arguments.

23. When it comes to decision-making I don't waste time speculating about options.

24. There are lots of things I'm too frightened to think seriously about.

25. Reasons are like cheap rental cars, there are plenty of them around and none are any good.

Appendix S

Engineering Design Observation Form

Engineering Design Elements	Period: Date:	Lesson / Activity:
Problem Definition	Rating 0-5	Notes:
Questioning		
Constraints		
Evaluation Criteria		
Solutions	Rating 0-5	Notes:
Research Existing		
Brainstorm Alternative		
Analysis / Modeling	Rating 0-5	Notes:
Prediction		
Uncertainty		
Estimation		
Experimentation	Rating 0-5	Notes:
Based on Analysis		
Empirical Data Gathering		
Prototyping		
Decision Making	Rating 0-5	Notes:
Evaluation of Solutions		
Optimizing		
Teamwork	Rating 0-5	Notes:
Working effectively		
Communication		

Appendix T

Rubric for Observation Form

Engineering Design Elements	Quantitative Rubric
Problem Definition	Rating 0-5
Questioning	0) None; 1) minimal, taken at face value; 3) multiple, quality judgment; 5) many, variety of sources, quality judged and documented
Constraints	0) None; 1) minimal awareness; 3) understood, considered broadly; 5) prioritized technical and non-technical
Evaluation Criteria	0) None; 1) subjective, narrow focus; 3) multiple, clearly established; 5) many, component and systems level
Solutions	Rating 0-5
Research Existing	0) None; 1) few, unrelated; 3) multiple, demonstrates transfer; 5) many, consider technical and non-technical components
Brainstorm Alternative	0) None; 1) few; 3) multiple, demonstrates transfer; 5) many, consider technical and non-technical components, creative
Analysis / Modeling	Rating 0-5
Prediction	0) None; 1) single issue; 3) multiple; 5) many, consider technical and non-technical components
Uncertainty	0) None; 1) considered and dismissed; 3) discussed; 5) tested (empirical evidence) and researched
Estimation	0) None; 1) not based in a conceptual understanding; 3) triangulated by research; 5) estimated based on a conceptual understanding of the system behavior
Experimentation	Rating 0-5
Based on Analysis	0) None; 1) manipulating variables in analysis; 3) comparing prediction to experimental results; 5) using data to refine design and model
Empirical Data Gathering	0) None; 1) no logical approach; 3) trial and error, data not recorded; 5) methodic approach and data recording
Prototyping	0) None; 1) not based in a conceptual understanding; 3) triangulated by research; 5) based on understanding system, balanced by tradeoffs and attempts to optimize and return to iterative nature of design
Decision Making	Rating 0-5
Evaluation of Solutions	0) None; 1) face value; 3) data used; 5) based on a clear matrix of alternatives and advantages/disadvantages
Optimizing	0) None; 1) face value; 3) based on matrix; 5) return to and evaluation of criteria, problem, constraints. Effort to establish best solution for problem.
Teamwork	Rating 0-5
Working effectively	0) None; 1) few students working; 3) leader, followers; 5) clearly established roles, but each students understands the big picture.
Communication	0) None; 1) poor and confusing; 3) between a few team members only; 5) multiple forms (sketch, verbal, etc) all students have access to the information

Appendix U

Professional Development Agenda

Day 1 Agenda: 9am – 6pm

1. Overview
    Center
    Objectives
2. Current research agenda
    Goals / Means / Data / Timeline
3. Compare and contrast STL design process with Engineering Design process
4. Detailed Description of each step in the Engineering Design Process (Poster)
5. Case Study (1) –Tufunk project: Sand Deposition
    Educated guessing vs. identifying variables and manipulating (speed of fall f(height), volume dropped)
6. Apply Engineering Design Model to Fall lessons
    Brainstorm connections between Fall activities and Engineering Design Steps
    Document connections in Lesson Plan Application matrix
    Verify appropriate mix of lessons and targets in Summary matrix
7. Discuss Achievement test and CM3 test
    Content and timeline for administration
8. Observation schedule qualitative and quantitative
    Purpose: Documentation / evaluation / feedback
    Adjustment to this classroom
9. Meet administration / secure written permission
    Deliver research proposal
    Data to be collected:
        Student transcripts (not end of level test results), Achievement, CM3, Teacher observations, teacher handouts, student generated documents and products
    Data ***not*** collected:
        Student photographs/video/audio, student personal information
10. Reflection / Evaluation
    Will the engineering design steps be implemented in the Fall?
        What further support can I provide?
        What areas of concern exist?

Day 2 Agenda: 9am – 4pm

1. Case Study (2) – compare core 3 and core 4
2. Review Lesson Plan Application form to verify accuracy
3. Develop model for understanding and analysis
    Identify pertinent variables and relate to Engineering Design
    Expand variables
    Establish tests for variables
4. Engineering tools
    Decision Matrix: Engineering Your Future, Gomez, page 361; Engineering Design, Dym, page 44; ZEUS page 7
    Modeling Example: Energy Model, Motion Model; ZEUS page 11-12
    Functions/Means Chart: Engineering Design, Dym, page120
    Functions/Means Tree: Engineering Design, Dym, page 85
    Constraints / Objectives Chart D.110
    Responsibilities Chart: Engineering Design, Dym page164
    Time Line Chart: Engineering Design, Dym page172
    Objective Tree: Engineering Design, Dym page 58
    Team Calendar: Engineering Design, Dym page167
5. Apply Engineering Design Model to Spring lessons
    Brainstorm connections between Spring activities and Engineering Design Steps
    Document connections in Lesson Plan Application matrix
    Verify appropriate mix of lessons and targets in Summary matrix
6. Reflection / Evaluation
    Will the engineering design steps be implemented in the Spring?
        What further support can I provide?
        What areas of concern exist?

Appendix V

Professional Development Objectives

Day 1

1. Communicate fundamental purpose and objectives of research study

2. Differentiate Technology Education Design from Engineering Design

3. Clearly articulate a relationship between Engineering Design and Fall activities

4. Provide opportunity for further clarification on Engineering Design

Day 2

1. Clearly articulate a relationship between Engineering Design and Spring activities

2. Establish appropriate model for Engineering Design Challenge

3. Clarify pertinent variables for model and expand variables

4. Provide opportunity for further clarification on Engineering Design

Appendix W

Fall Engineering Design Lesson Application Matrix

Engineering Design Elements	Lesson / Activity: Magnetic Levitation
Problem Definition	
Questioning	Students are not provided with a clear understanding of how the systems works and therefore they discover the need to ask questions to define how things work – this point is driven home in a reflective discussion facilitated by the teacher.
Constraints	Students recognize that they are limited in design/construction/testing time. They identify constraints as shown in handout – design and materials. Students discover additional constraints such as limited power, width, fan blades, run time of motor.
Evaluation Criteria	Traverse 14 foot track in shortest time.
Solutions	
Research Existing	Students find display case with previous winners and are encouraged to spend some time online searching for other solutions.
Brainstorm Alternative	Students individually brainstorm, sketch and write down ideas in design journal
Analysis / Modeling	
Prediction	Class discussion of pertinent variables included: such as F=MA, Drag (aerodynamic), Friction from moving components, Electrical connections and what impacts their efficiencies.
Uncertainty	Students "randomly" experiment with variables such as car width, wider = more stable, but more friction against track. Use 3 runs to establish an average. This random experimentation is followed up during the reflective discussion to establish a need for understanding the governing principles behind the system behavior.
Estimation	Students may not have equipment or time to measure air resistance, but are encouraged by discussion / lecture how to estimate qualitatively how to reduce air drag.
Experimentation	
Based on Analysis	Student journals connect design decisions to variables discussed in class. The reflective component entitled, "modifications and things learned" includes talk of manipulating variables such as drag, friction, mass, balance, width, number of magnets/weight, center of gravity, position of motor for balance, etc. and the impact on performance.
Empirical Data Gathering	Students make multiple speed runs of car and make modifications. The results translate into improvements in design.
Prototyping	Students build car and make 3 runs during the race; compute average speed.
Decision Making	

Evaluation of Solutions	Student journal shows variables, designs and justifies why one was chosen over others.
Optimizing	Students reflect on their design choices and discuss how they weigh advantages and disadvantages to make decisions.
Teamwork	
Working effectively	Students share track but work individually on this project.
Communication	Sketches and written documentation included in design journal. The sketches and ideas are documented in the design notebook. This includes brainstorming and justification of design choices. Includes details on deviation from original plan.
General Comments	This project is designed for students to understand the need for design, planning, precision and general governing physics principles. This is a challenging project that makes random trial and error difficult and relatively unsuccessful. Discussion follows this challenge regarding the need for understanding the applied physics, problem definition, and analysis of variables involved to reduce random guessing.

Engineering Design Elements	Lesson / Activity: Electric Motors
Problem Definition	
Questioning	
Constraints	Materials and time line are clearly specified.
Evaluation Criteria	Maximize horsepower with power provided; minimize power required to operate motor (overcome frictional loses)
Solutions	
Research Existing	Students can observe previous solutions and through handouts and other sources explore how an electric motor works.
Brainstorm Alternative	Students are encouraged to make sketches of modifications in their design journal.
Analysis / Modeling	
Prediction	Students calculate horsepower as a function of their motor lifting a mass by a distance. Equations assist in converting grams to pounds, and then foot * pounds to horsepower. Motors are run at minimum power to establish a numerical baseline for drag. Motors are run 5 minutes to establish a baseline for heat generation and dissipation.
Uncertainty	Students add weight to their horsepower calculations until a reduction in power occurs. A graph is generated and a plot of weight – horsepower shows a curve with a peak. The peak is the max horse power and therefore the “power band” of their motor design.
Estimation	
Experimentation	
Based on Analysis	Student manipulate variables such as brush type, pressure, coil balance, feet of wire, gaps of field windings and armatures in order to experiment with performance.
Empirical Data Gathering	Data for horsepower calculations are gathered by lifting weights and timing
Prototyping	Motors are built, tested and modified
Decision Making	
Evaluation of Solutions	Students manipulate variables such as brush type, pressure, coil balance, feet of wire, gaps of field windings and armatures in order to calculate hp and therefore develop the optimal design
Optimizing	Done initially by minimizing run power, then by HP calculations. Testing includes both series and parallel wound motors.

Teamwork	
Working effectively	Students participate in teams of two. Teacher encourages team work by explaining the importance of each student working toward the goal in order to finish the project on time. Teacher encourages students to divide the responsibilities and roles.
Communication	Students use verbal and graphic (sketches) during the project and written during the journal and reporting.
General Comments	Students report how they changed the plans to increase their motor's horsepower. Students use sketches to explain their changes.

Engineering Design Elements	Lesson / Activity: Solar and Gearing
Problem Definition	
Questioning	
Constraints	Use materials provided in the specified time limits
Evaluation Criteria	Convert light energy to electrical energy, maximize horsepower calculations using optimal power source.
Solutions	
Research Existing	
Brainstorm Alternative	
Analysis / Modeling	
Prediction	Gear ratios are calculated and a related worksheet connects this power and gear ratio activity to the MPH calculations as they relate to wheel circumference and motor RPM. Predictions are made regarding the best (most powerful) setup for calculating horsepower of a winch powered by solar cells – parallel, series/parallel, or series. In theory all are equal watts, but due to motor specifications, different voltage/amperage combinations yield different horsepower results. A plot is generated comparing voltage against horsepower. Students are introduced to an energy model representing energy in=energy out. Thus relating power from panels to losses due to friction and specifically various points where friction exists.
Uncertainty	Students generate a curve representing the relationship between power and distance between cell and light source. This will be plotted on graph paper.
Estimation	Students use a heuristic of 1200 watts / meter sq and estimate the power of their cells to compare their results to the known values of typical solar arrays….Thus calculating efficiency. Students also build a hand powered winch which they operate to feel gear ratios and estimate problems related to gearing too high or too low for their cars – thus introducing mechanical advantage.
Experimentation	
Based on Analysis	Students apply their understanding of P=IV to estimate that power will be equal regardless of the series or parallel wiring.
Empirical Data Gathering	Measure volts and amps and distance to light for plotting
Prototyping	Students setup multiple cells in series and parallel to record volts and amps and calculate power.

Decision Making	
Evaluation of Solutions	Students attempt to maximize horsepower by evaluating different wiring configurations.
Optimizing	Students will conclude that distance (proximity) is a critical variable in increasing power output of solar panels.
Teamwork	
Working effectively	Students work in teams of four. Each student in the team is assigned responsibilities and a team leader is established.
Communication	Students log data and experiments in their notebook as they work through the problem.
General Comments	This activity provides a connection to the electrathon challenge as it high lights relationships between efficiency and power (varying voltage/amperage). It also introduces rolling resistance and the need to minimize its effect.

Engineering Design Elements	Lesson / Activity: Solar Lego Car
Problem Definition	
Questioning	Students are encouraged to document their questions regarding how to reduce the cost of friction, rolling resistance, weight and other pertinent variables.
Constraints	Materials, time
Evaluation Criteria	Speed calculated by a preset distance
Solutions	
Research Existing	Students see previous year's cars and discuss pros/cons of design. Gearing system based on results from solar project just completed
Brainstorm Alternative	Students brainstorm with sketches and conversations.
Analysis / Modeling	
Prediction	Variables include reducing friction, weight of system (including wheels), size of tires. Based on HP calculations from solar experiment for best voltage/amperage combination for car.
Uncertainty	Class discussion why results from previous solar experiments may or may not be accurate, possible errors are discussed. This leads to conclusions based on triangulation of team results and an accumulated body of knowledge from previous years.
Estimation	
Experimentation	
Based on Analysis	Equation is developed which starts with F=MA, then force is explored by discussion to be reduced by rolling resistance and increased by proximity of light source to solar cells. Rolling resistance is a factor of tire material, tire width, size (relating to gear ratio). Student teams develop an equation to represent their car's performance. Students measure rolling resistance by running car down an incline and measuring angle required to initiate movement. The tangent of this angle provides a value for frictional coefficient which is mathematically converted into friction force.
Empirical Data Gathering	Student time car runs
Prototyping	Students develop fast car
Decision Making	
Evaluation of Solutions	Changes are evaluated in terms of car speed
Optimizing	Each change effects speed leads to understanding of optimizing variables

Teamwork	
Working effectively	Teacher encourages participation, team roles are established, definition of leadership and follower ship is explained. Team members delegate responsibilities. Students become experts in different areas of the car and rely on each other's expertise.
Communication	Journal includes student reflection and variables involved with making their car go it's fastest. Written, sketches, brainstorming, evaluation, personal reflection.
General Comments	The equation representing performance serves as a model for the electric car in the spring challenge.

Engineering Design Elements	Lesson / Activity: 1/10 Scale Model
Problem Definition	
Questioning	Students work in teams to establish a problem definition based on their goals and “need”. Students determine what function the car will serve, how the components will be organized, and question the rules and parameters set by the instructors. Students must answer questions about driver position, balance between height = comfort and frontal surface area. How to steer using levers or rack/pinion or other solutions. Questions must be answered to balance between the 1/10 model and the full size car.
Constraints	Students are constrained to build a model that they could use for their full size design, limited materials, skills and time must be considered. Accuracy of the model will limit potential future construction difficulties as they are forced to be able to physically produce the idea. Each part must be scaled by 1/10 in order to receive full credit.
Evaluation Criteria	Steering must be functional. All required components must be accurately scaled, presentations must be complete and organized, and teams must be functional.
Solutions	
Research Existing	Students investigate previous designs, use the internet and various handouts to explore existing solutions to the design in the form of both the model and full size design. Students drive previous year’s cars and discuss their functionality and comfort including how and why. Discussion uses analogies to compare possible component designs to familiar solutions such as lawn mowers, golf carts, fork lifts, etc.
Brainstorm Alternative	Students verbally brainstorm and sketch ideas. They explore potential solutions and discuss limits and methods of dealing with issues/solutions. Brainstorming methods are discussed with the students and teacher encourages good brainstorming habits.
Analysis / Modeling	
Prediction	Students use wind tunnel testing to evaluate drag on their foam model plug prior to creating a body shell. This prediction is based on a discussion and demonstration of the wind tunnel using various shapes with similar cross sectional areas.
Uncertainty	
Estimation	Teams draw a scale version of the driver(s) and have this photocopied. With the agreed upon driver and driver position, a frame and body are drawn by each team member on the photocopies. The frame design and body design are estimated and discussed by team members. Finally a physical model of the frame confirms team decisions regarding placement of parts and fit of driver.

Experimentation	
Based on Analysis	Rider position and mechanical function are documented in the form of pros and cons when students observe previous solutions. This serves as a basis for initial designing of the frame. Body shapes, tested in the wind tunnel for drag coefficients serve as a starting point for body designs, balancing air resistance against practicality.
Empirical Data Gathering	Drag is measured on their car body and different shapes are created for minimal resistance. Dimensions are gathered from the “driver” and scaled to create specifications for the model driver.
Prototyping	Multiple revisions are made to the scale model as students debate and work toward an optimal design for their problem definition and team constraints. All scale components are created, ie: battery, motor, wheels, steering, frame, body. These components are arranged and rearranged until team agrees upon design, initially starting with sketches.
Decision Making	
Evaluation of Solutions	Solutions are evaluated using a decisions matrix based on team established criteria and design alternatives.
Optimizing	Tradeoffs between low frontal surface area and driver comfort are addressed. Air resistance and body size are estimated using the tunnel and modeling placement of each component.
Teamwork	
Working effectively	Students work in groups of 2-3 and utilize a responsibilities chart to assign (manage) roles and tasks. Systems are broken down into subsystems for ease of construction and analysis. Students use a time management calendar.
Communication	Students communicate verbally, by sketching, and using responsibilities charts and decision matrix when appropriate. Teams make design presentation and explain and justify their choices.
General Comments	This project serves as a model for the full size car, showing special relationships and functional steering mechanisms.

Appendix X

Professional Development Evaluation

Day 1

How well were the following objectives addressed?
Please rate the following objectives from 1 to 5 by circling your response.
(1: Very poorly, 3: Limited extent, 5: Very well)

1. Communicate fundamental purpose and objectives of research study.
1 (Very Poorly) 2 3 4 5 (Very Well)

Comment:

2. Differentiate Technology Education Design from Engineering Design.
1 (Very Poorly) 2 3 4 5 (Very Well)

Comment:

3. Clearly articulate a relationship between Engineering Design and Fall activities.
1 (Very Poorly) 2 3 4 5 (Very Well)

Comment:

4. Provide opportunity for further clarification on Engineering Design.
1 (Very Poorly) 2 3 4 5 (Very Well)

Comment:

General Comments:

Day 2:

PD Evaluation: Fall 2007 (used 2nd day Summer and fall)

How well were the following objectives addressed?
Please rate the following objectives from 1 to 5 by circling your response.
(1: Very poorly, 3: Limited extent, 5: Very well)

1. Clearly articulate a relationship between Engineering Design and Spring activities.
    1 (Very Poorly)   2   3   4   5 (Very Well)

Comment:

2. Establish appropriate model for Engineering Design Challenge.
    1 (Very Poorly)   2   3   4   5 (Very Well)

Comment:

3. Clarify pertinent variables for model and expand variables.
    1 (Very Poorly)   2   3   4   5 (Very Well)

Comment:

4. Provide opportunity for further clarification on Engineering Design.
    1 (Very Poorly)   2   3   4   5 (Very Well)

Comment:

General Comments:

Appendix Y

California Measure of Mental Motivation Score Interpretation

CALIFORNIA MEASURE OF MENTAL MOTIVATION

Score Interpretation Document

Scale Descriptions

1. Mental Focus

The person scoring **high** in *mental focus* is diligent, focused, systematic, task-oriented, organized and clear-headed. While engaging in a mental activity he/she tends to be focused in their attention, persistent, and comfortable with the problem solving process. This person tends to **agree** with the statement:

"It is easy for me to organize my thoughts."

Those persons scoring **low** on this scale show a compromised ability to regulate their attention and a tendency toward disorganization and procrastination. These individuals may also express frustration with their ability to approach solving problems. This person tends to **agree** with the statement:

"My trouble is I stop paying attention too soon."

The Mental Focus scale consists of three non-orthogonal (correlated) factors. These factors are **Process**, **Organization**, and **Attention**.

Process: The person scoring **high** on *Process* feels at ease with engaging in problem solving. This person does not become overwhelmed when faced with a difficult or complex problem. She/he moves through the process of problem solving without getting daunted along the way and is comfortable making decisions when necessary. A **low** score on *Process* reflects frustration and a sense of being overwhelmed by complex problems.

Organization: The person scoring **high** on *Organization* is systematic and ordered. This person's sense of organization contributes to the self-perception of being capable of meeting deadlines and completing work in a timely fashion. A **low** score on *Organization* represents a muddled, poorly managed approach to problem solving and classroom assignments.

Attention: The person scoring **high** on *Attention* is focused and clear-headed. Rather than procrastinating when making decisions, this individual has a sense of personal diligence. A **low** score, on the other hand, reflects a person who struggles with maintaining his/her concentration on a task, has trouble persisting with an activity to reach completion and often procrastinates.

2. Learning Orientation

The person scoring high in *learning orientation* is motivated by a desire to increase their knowledge and skill base. This individual values learning for learning's sake and express an eagerness to engage in the learning process. These individuals express an interest for engaging in challenging activities, and endorse information-seeking as personal strategy when problem solving. These individuals tend to **agree** with the statement:

"I can learn a whole lot more than I already know."

Those individuals scoring **low** on *learning orientation* tend to have a muted desire to learn about new or challenging topics. The express a lack of willingness to explore or research an issue. These individuals may even purposefully avoid opportunities to learn and understand. These individuals will attempt to answer questions with the information they have at hand rather than seeking out new information. These individuals tend to **disagree** with the statement:

"Before reaching a conclusion, I will gather as much information as possible."

This scale consists of two non-orthogonal (correlated) factors. These factors are **Desire to Learn** and **Information Gathering**.

Desire to Learn: The person scoring **high** in the *Desire to Learn* values the learning process as a means to accomplish mastery over a task. Inquiry guides their interests and activities. He/she is intellectually curious and feeds this curiosity with research and active exploration. Those individuals scoring **low** on *Desire to Learn* tend to express less curiosity and interest in learning. They are likely to feel thwarted by challenging activities when their attempts are not met by success, or likely to avoid challenge altogether.

Information Gathering: The person scoring **high** in *Information Gathering* values information and evidence gathering, they recognize the importance of giving reasons to support a position, and they are likely to be actively engaged in school. These individuals appreciate clarification and understanding of relevant information as critical to the decision making process. A **low** score on *information gathering* represents the tendency to come to a decision without collecting all relevant information and considering all the available evidence. This person may actively avoid such information gathering, may not recognize the importance of such activity prior to reaching a decision, or may feel unable to perform such an activity.

3. Creative Problem Solving

Persons scoring **high** on *Creative Problem Solving* have a tendency to approach problem solving with innovative or original ideas and solutions. They pride themselves on their creative nature, and this creativity is likely to manifest itself by a desire to engage in challenging activities such as puzzles, games of strategy, and understanding the underlying function of objects. For these individuals, there is a stronger sense of personal satisfaction from engaging in complex or challenging activities than from participating in activities perceived to be easy. These individuals tend to **agree** with the statement:

> "I really enjoy trying to figure out how things work."

A **low** score on Creative Problem Solving reflects the absence of feelings of personal imaginativeness or originality. This manifests itself by the tendency for these individuals to avoid challenging activities. They will choose easier activities over challenging ones. These individuals tend to **agree** with the statement:

> "I hate dealing with anything that is complicated."

This scale consists of two non-orthogonal (correlated) factors. These factors are **Innovation**, and **Challenge Seeking**.

Innovation: The person scoring **high** in *Innovation* has a sense of confidence in their ability to solve difficult problems. They report that they tend to identify alternatives and take creative and innovative paths to solve problems. These individuals pride themselves on being imaginative, ingenious, and original. **Low** scores on *Innovation*, on the other hand, reflect the tendency to report that one's paths to problem solving are not, in that person's view, particularly original or creative. Of particular concern with low scores would be the individual's general sense that he/she struggles with identifying alternatives and solving problems.

Challenge Seeking: Individuals scoring **high** in *Challenge Seeking* have a preference for challenging and complicated activities. These individuals are eager to engage in challenging activities and choose challenging activities over easier ones. These individuals receive enjoyment and self-satisfaction from engaging in the process of problem solving. This enjoyment of process is likely to be separate from, or in addition to, the benefits achieved by coming to solution (e.g. increasing one's knowledge base and skills). Individuals who express a dislike for or even a hatred for complex, complicated and challenging pursuits receive **low** scores on *Challenge Seeking*. This disdain for challenge may manifest itself in the tendency for these individuals to avoid puzzles or games of strategy, in exchange for tasks that are perceived to be of greater ease.

4. Cognitive Integrity

Individuals scoring **high** in *Cognitive Integrity* are motivated to use their thinking skills in a fair-minded fashion. They are positively disposed toward seeking the truth and being open-minded. These individuals are comfortable with complexity, and they enjoy thinking about and interacting with others with potentially varying viewpoints in the search for truth or the best decision. These individuals tend to **disagree** with the statement:

> "Others have a right to their ideas, but I do not need to hear them."

Those individuals scoring **low** on this scale express a viewpoint that is best characterized as cognitive resistance. They are hasty, indecisive, uncomfortable with complexity and change, and are likely to be anxious and close-minded. These individuals tend to **agree** with the statement:

> "I know what I think, so why should I pretend to consider choices."

This scale consists of two non-orthogonal (correlated) factors. These factors are **Curiosity**, and **Fair-mindedness**. Both of these factors are measured by a preponderance of items that represent the opposite of Inquisitiveness (e.g. mental apathy) and Openmindedness (closemindedness). As a result, individuals tending to consistently disagree with scale items receive high scores on these factors.

Curiosity: The person scoring **high** in *Inquisitiveness* expresses strong intellectual curiosity. They recognize the relevance of considering alternative perspectives. In addition, these individuals acknowledge that despite their current abilities, they have the capacity for increasing their knowledge base. At a meta-cognitive level they appear to appreciate the personal value of pursuing challenging activities, even when others have already reached conclusion. Individuals who ignore or devalue the opinions held by others, and express a general mental laziness when it comes to solving problems are likely to receive **low** scores on this factor.

Fair-mindedness: Individuals scoring **high** in *Openmindedness* express the desire to be fair to all ideas, even when one of the ideas is their own. Persons scoring high on this factor espouse the position that it is important to put aside one's preconceived notions, or suspend judgment in favor of considering alternative choices and viewpoints. Individuals who freely assert their inability or disinclination to challenge their belief systems receive **low** scores on this factor.

Score Interpretation

Please use the following guidelines for interpreting your results.

All scores reported for the CM3 scales are on a 50-point metric. We report overall scores for each of the four scales as well as factor (or sub-scale) scores for each scale. Overall scores for each scale are averages (arithmetic means) of the associated factor scores.

Scores ranging from 0 to 9 points represent individuals who are strongly negatively disposed toward the particular attribute. Scores ranging from 10-19 represent individuals who are somewhat negatively disposed toward the attribute. Scores ranging from 20 to 30 points represent persons who are ambivalent toward the dispositional attribute. Scores ranging from 31 to 40 points represent individuals who are somewhat disposed toward the attribute, and scores of 41 and above represent individuals who are strongly disposed toward the attribute.

SCORE ON CM3 SCALE	INTERPRETIVE CATEGORY
0-9	Strongly Negative
10-19	Somewhat Negative
20-30	Ambivalent
31-40	Somewhat Disposed
41-50	Strongly Disposed

CURRICULUM VITAE

NATHAN J. MENTZER

Utah State University
Engineering & Technology Education
UMC 6000
Logan, Utah 84322-6000

College of Engineering
Industrial Science, 007
Mobile: (406) 546 - 6576
nmentzer@comcast.net

E D U C A T I O N

Expected 2008 **Ph.D., Education, Curriculum and Instruction**
Emphasis: Engineering & Technology Education
Department of Engineering & Technology Education
Utah State University
Fellow, National Center for Engineering & Technology Education
Advisor: Kurt Becker, Ph.D.

2001 **M.S., Education, Curriculum and Instruction**
Emphasis: Technology Education
Professional Paper: Impact of PT3 Professional Development Activities on Teacher Education Faculty at Montana State University - Bozeman
Department of Education
Montana State University
Advisor: Scott Davis, Ph.D.

1999 **B.S., Technology Education**
Department of Education
Montana State University
Advisor: Scott Davis, Ph.D.

P R O F E S S I O N A L   E X P E R I E N C E

2007 **National Center for Engineering and Technology Education**
Graduate Student Workshop
* Dr. Karen Zuga & NSF Program Officers
* Ms. Patti Curtis & Boston Museum of Science.

2007 **Surveying the landscape: The nature and status of K-12 Engineering Education in the United States**

*Reviewer of *Engineering the Future: Designing the World of the 21st Century*.
*Supervisor: Dr. Ken Welty
*NCETE National Landscape Study for the National Academy of Engineering.

2005-2007 **Undergraduate Recruitment for Utah State University**

*Prepared recruiting presentations
*Delivered presentations to high school students in Utah

2006 **Professional Development Independent Contractor**

Darby Public School District, Montana
* Taught 6 day CAD/CAM workshop
Helena College of Technology, Montana
* Taught 3 day CAD/CAM workshop

2006 **Brigham Young University**

Provo, Utah
National Center For Engineering & Technology Education
* Professional development staff
* Co-taught 10 day engineering workshop

2005 **Montana Tech**

Rocky Mountain Agile Virtual Enterprise
Creativity Force, Butte, MT
* Co-taught 5 day concurrent engineering workshop

2000 - 2005 **Darby Public School District**

Darby High School & Junior High, Darby, MT
7-12 Technology Education Teacher
Developed and taught curriculum for the following classes:
* 8th Grade Technology Education
* 9th Grade Technology Education
* CAD/CAM I, II, III, IV
* Transportation Technology I, II
* Metal Fabrication
* Production Technology

Other responsibilities:
* Grant writing in excess of $130,000
* Adult education instructor
* Destination Imagination team coach
* New teacher mentor
* Student teacher supervisor

Fuels for School Project (http://www.fuelsforschools.org)
* Collaborated in grant writing and planning phase
* Developed and implemented curriculum integrating biomass fuel heating

2003 - 2008 **Cooper Firearms Inc., Montana**
CFI, Stevensville, MT
* Independent Contractor
* CNC programming and prototyping

2000 **Graduate Teaching Assistant**
Montana State University, Bozeman, MT
* Taught TE410 CAD/CAM
* Lab assistant TE113 Electronics/Networking
* Professional development training for faculty
* Co-advisor of technology education club

1999 **Internship Blaine County School District**
Wood River Middle School, Hailey, ID
* Taught: Advanced Tech, Tech, 6th Tech, Publications
* Introduced digital video production
* Produced digital video documentary on WRMS Tech
* Actively investigated integration of math and science
* Camp counselor for Natural Helpers camp
* Team taught with Brad Thode & Doug Walrath

Ernest Hemingway Elementary, Ketchum, ID
* Developed hydroponics system and curriculum
* Developed lessons: flight, simple machines & bio-tech
* Worked daily with parents volunteering in the classroom
* Team taught with Terry Thode, Grade K-5

1997 **Student Advisor with C.A.R.E. Program**
California University, California, PA
* Advised students with special needs
* Coached academic and social development

1996 **Early Field Internship**
Ambridge Area High School, Ambridge, PA
* Developed & taught lessons
* Evaluated student learning

1996 **Summer Camp Technology Teacher**
Millersville University, Millersville, PA
* Worked with inner city youth
* Taught students in coordination with Dr. McCade

AWARDS

2007 **Donald Maley Spirit of Excellence, Outstanding Graduate Student**
* International Technology Education Association

2004 **Educator of Distinction Award**
* Exemplary Dedication to the Field of Education
* Coca-Cola Scholars Foundation

2003 & 2005 **Teacher of the Year Award**
* Darby High School Student Council

2003 **Outstanding High School Teacher**
* Darby Civic Group

2002 **Polette / Armstrong Award**
* Technology Education Association of Montana

1999 **Most Outstanding Senior in Secondary Education**
* Based on academic performance
* Montana State University

1999 **Leo L. Knuti Scholarship**
* Based on academic performance
* Montana State University

PUBLICATIONS

2008 Mentzer, N., Mentzer, F., & Jones, K. (2008). Join the Mission, Design a Patch. *Technology and Children, 12*(4).

2008 Daugherty, D. & Mentzer, N. (2008). Analogical Reasoning in the Engineering Design Process and Technology Education Applications. *Journal of Technology Education, 19*(2), 6-20.

PRESENTATIONS

Mentzer, N. (2008, May). *Academic performance as a predictor of student growth in Achievement and Mental Motivation during an engineering design challenge in Engineering and technology education.* Research in Engineering and Technology Education Student. Conference; University of Minnesota, St. Paul, Minnesota.

Walrath, D., Mentzer, N., & Swapp, A. (2008, February). *Dust in the Wind: Exploring Renewable Energy*. International Technology Education Association Conference; Salt Lake City, UT.

Hailey, C., Mentzer, N., & NCETE Doctoral Fellows. (2008, February). *Engineering Design Challenge: Infusing Engineering into Technology Education.* NCETE Research Symposium: International Technology Education Association Conference; Salt Lake City, UT. Accepted for presentation

Erekson, T., Mentzer, N. (May, 2007). *Engineering Design: Student Capabilities and Perceptions; Research reactor.* National Center for Engineering and Technology Education Summer Workshop. University of Illinois at Urbana-Champaign.

Zuga, K., Mentzer, N., & NCETE Doctoral Fellows. (2007, March). *A Comparative Analysis of Novice and Expert.* NCETE Research Symposium: International Technology Education Association Conference; San Antonio, TX.

Mentzer, N., & Stewardson, G. (2007, March). *Technological Literacy and USU General Education Students.* International Technology Education Association Conference; San Antonio, TX.

R O U N D T A B L E S

Stricker, D., Mentzer, N., Walrath, D., & Kelley, T. (2008, May). *Building on Current Research in Engineering and Technology Education.* Research in Engineering and Technology Education Student Conference; University of Minnesota, St. Paul, Minnesota.

Walrath, D., Mentzer, N., Daugherty, J., Denson, C., & Stricker, D. (2007, August). *NCETE PhD Cohort #2 Fellows Orientation Roundtable*. Utah State University, Logan, UT.

Mentzer, N., Walrath, D., Daugherty, J., Kelley, T., Denson, C., & Zeng, Y. (May, 2007). *Necessary Tensions: Moving the Field (ETE) Forward*. National Center for Engineering and Technology Education Summer Workshop. University of Illinois at Urbana-Champaign.

P R O F E S S I O N A L   A F F I L I A T I O N S

Current — **International Technology Education Association**

1997 - 2005 — **Technology Education Association Montana**
Professional Teachers Association
- * President 2004-2005
- * Vice president 2003-2004
- * Secretary / Treasurer 2002-2003

1989 - 2005	**Technology Student Association** * Darby TSA club advisor 2000-2005 * Attended state competition 1999 * Collegiate judge 1995-1997 * Attended national convention 1995, 1997 * Pennsylvania state president 1994-1995 * Pennsylvania state vice president 1993-1994 * Competed in local, state conferences 1989-1995
1997 & 1996	**Technology Education Association of California** California University of Pennsylvania * President * Treasurer

S U C C E S S F U L   G R A N T S

2002	**Steele Reese Foundation** Funding $35,000 Project Objectives: * Purchase a CNC Lathe * Develop automation curriculum * Facilitate professional development for local machinists * Utilize high school students as teaching assistants
2001	**Montana Community Foundation** Funding $30,000 Project Objectives: * Purchase a CNC Mill * Develop automation curriculum * Facilitate adult education * Utilize high school students as teaching assistants
2001	**Forest Service – Rural Community Assistance** Funding $13,000 Project Objectives: * Construct a greenhouse – biotechnology Lab * Study hydroponics
2001	**Toyota Tapestry Grant (Co-Author)** Funding $10,000 Project Objectives: * Construct a greenhouse – biotechnology Lab * Study hydroponics
2000 - 2005	**Carl Perkins Annual Allocation** Funding $90,000 Coordinated and authored district grant annually

2002	**Rapp Family Foundation** Funding $2,000 Project Objectives: * Construct a greenhouse – biotechnology Lab * Study hydroponics
2002 & 2003	**Carl Perkins Non-Traditional Education Mini-Grant** Funding $1,500 & $1,200 Project Objectives: * Facilitate a CAD/CAM Summer Workshop * Enroll female students Grade 9-12
2003	**Rapp Family Foundation** Funding $1,000 Project Objectives: * Design, construct, test and race electric vehicles
2002	**Northwestern Energy** Funding $1,000 Project Objectives: * Design, construct, test and race electric vehicles