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## Identifying the Essential Aspects and Related Academic Concepts of an Engineering Design Curriculum in Secondary Technology Education

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EDUCATION

# Research in Engineering and Technology Education

**IDENTIFYING THE ESSENTIAL ASPECTS AND  
RELATED ACADEMIC CONCEPTS OF AND  
ENGINEERING DESIGN CURRICULUM IN  
SECONDARY TECHNOLOGY EDUCATION**

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UNIVERSITY OF GEORGIA, 2007**



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ESSENTIAL ASPECTS AND RELATED ACADEMIC CONCEPTS OF AN ENGINEERING  
DESIGN CURRICULUM IN SECONDARY TECHNOLOGY EDUCATION

by

PHILLIP CAMERON SMITH, JR.

(Under the Direction of ROBERT C. WICKLEIN)

ABSTRACT

Technology education is a field of study which seeks to promote technological literacy for all students. Some recent research in the field has focused on integrating content and methodology from engineering design into technology education classes, particularly at the secondary level. This study contributes to the research base in technology education on the subject of incorporating the engineering design process into the technology education curriculum. It addressed the need for the development of a framework for understanding engineering design and the related academic concepts that can be used by professionals in the field of technology education seeking to incorporate the engineering design process into the technology education curriculum. The purpose of this study was to address the question “What are the essential aspects and related academic concepts of an engineering design process in secondary technology education curriculum for the purpose of establishing technological literacy?”

A four-round Delphi process was the research methodology employed in this study to give multiple opportunities for the group opinion to coalesce. The resulting data from the Delphi process was analyzed and categorized. Only those items that met strictest criteria for high median score, low interquartile range, and consensus were accepted as very important and considered in the conclusions and recommendations. Participants in this study identified forty-eight items that met these strict requirements.

The conclusions made from this study were related to the integration of engineering design into secondary technology education classes. The recommendations fell into three categories: future research, instructional delivery methods, and teacher preparation.

INDEX WORDS: technology education, engineering design process, secondary education, mental processes, and Delphi process

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by

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2006

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Most importantly, I would like to thank God for the opportunities He has given me. He has given me an eternal relationship with Him through simple faith in Jesus, a wonderful family, and the chance to enjoy so many things in this life.

*Trust in the Lord with all your heart and  
lean not on your own understanding;  
in all your ways acknowledge Him, and  
He will make your paths straight.*

Proverbs 3:5-6



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## CHAPTER 1

### INTRODUCTION

Technology education is a field of study that seeks to promote technological literacy for all students. According to a recent study, in the United States technology education is part of the state framework for 38 states, there are approximately 35,909 middle or high school technology teachers, and technology education is most frequently an elective course (Meade & Dugger, 2004). Indeed, “Technology education provides an opportunity for students to learn about the processes and knowledge related to technology that are needed to solve problems and extend human capabilities” (ITEA, 1996, p. 13). Wright and Luada (1993) defined technology education as a program designed to help students “develop an understanding and competence in designing, producing, and using technological products and systems, and in assessing the appropriateness of technological actions” (p. 4).

The processes associated with technology have become key elements in technology education curriculum. A guiding influence in the development of this process-based curriculum has been the Technology for All Americans Project (Lewis, 1999; Loepf, 2004; Satchwell & Dugger, 1996; Wamsley 2003). With the publication of *Technology for All Americans: A Rationale and Structure for the Study of Technology* (ITEA, 1996), the suggested structure for the study of technology became the Universals of Technology which were identified as the processes, knowledge, and context associated with the development of technological systems:

The processes are those actions that people undertake to create, invent, design, transform, produce, control, maintain, and use products or systems. The processes include the human activities of designing and developing technological systems; determining and controlling the behavior of technological systems; utilizing technological systems; and assessing the impacts and consequences of technological systems. (p. 16)

Thus, solving problems in the context of technological systems has been identified as a key aspect of the curriculum commonly associated with technology education (Sanders, 2001). Activities that involve solving problems have been called the “philosophical nucleus” (Dugger, 1994, p.7) of technology education. Hill (1997) indicated that solving problems remains a major component of technological literacy.

Although this structure has been provided for the field, various paradigms for delivering the curriculum of technology education exist (Bensen, 1995; Devore, 1968; Hatch, 1988; Maley, 1973; Dyrenfurth, 1991; Savage & Sterry, 1990; Sydner & Hales, 1981; Wicklein & Rojewski, 1999). The actual practice of technology education in the United States has been a somewhat eclectic mix of approaches and instructional methods (Foster & Wright, 1996; Sanders, 2001). Bensen (1995) found that some programs operated with a singular concept of technology in which all the supporting parts of the curriculum were related to the whole. Others were characterized by a plural concept in which various technologies are emphasized without an effort to relate them to the larger picture of technology and its effect in our world. *The Standards for Technological Literacy* (ITEA, 2000) do not mandate a particular curricular approach (Laporte, 2001) and technology education programs in the United State employ various approaches (Boser, Palmer, & Daugherty, 1998; Satchwell & Dugger, 1996). This fragmented focus and lack of a clear curriculum framework have been detrimental to the potential of the field and have hindered efforts aimed at achieving the stated goals of technological literacy for all students.

#### *Emergence of Engineering Design in Technology Education*

In recent years there has been a growing emphasis in the literature of technology education not only on the process of problem solving but also, more recently, on the integration of subject matter from various disciplines within those activities (Cotton, 2002; Engstrom, 2001; ITEA, 2003; Merrill & Comerford, 2004). This development leads to many questions for the field of technology education regarding the nature of the curriculum being offered and the proper approaches to take in administering that curriculum in technology education classrooms. As the

field has begun to broaden its perspective and embrace ties with other disciplines, the topic of engineering design has begun to appear frequently in the literature (Dearing & Daugherty, 2004).

Engineering design is not simply a frequent topic in the literature of technology education; it has already begun to be included in the curriculum in some areas. Some states have adopted technology education curriculum models that are pre-engineering in nature (Lewis, 2004). Project Lead The Way, Career Academies that emphasize engineering, engineering magnet schools, and other conceptions such as the “Stony Brook” model are all examples of engineering content making its way into the middle and high school curricula (Lewis, 2004).

Another recent development has been the funding and establishment by the National Science Foundation of the National Center for Engineering and Technology Education (NCETE). One of the main goals of this organization is to “work with engineering and technology educators to prepare them to introduce engineering design concepts in Grades 9-12” (Hailey, Erekson, Becker, & Thomas, 2005, p. 24). Currently, nine universities and numerous additional high schools across the country are NCETE Partners working to develop and disseminate materials, educate teachers, train future teacher educators, and facilitate relationships between the fields of engineering and technology education. The NCETE is also conducting several research studies beginning in 2005 related to engineering design in technology education.

Conceptually, there are close ties between engineering and the field of public education known as technology education since “both engineering and technology treat solving practical problems as their philosophical nucleus” (Dugger, 1994, p. 7). In fact, engineering has been defined as “the profession in which knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind” (Accreditation Board Engineering & Technology, 1986, p. 1). Engineers have been described as “creative problem solvers, often imagining and designing new technologies as a means to solve problems” (Burghardt, 1999, p. 1).

Thus, solving problems is an intrinsic component of both technology education and the field of engineering.

However, it is evident from an examination of the literature that there are certain aspects inherent to the engineering design process which are not included in technological problem solving (Fales, Kuetemeyer, & Brusica, 1999; Wright, 2002; Hailey et al., 2005). Technology educators have indicated the need for further explanation of these differences (Wicklein & Gattie, 2004) in order to gain the expertise necessary to be able to incorporate the engineering design process in technology education classrooms.

#### Purpose of the Study

This study contributed to the research base in technology education on the subject of incorporating the engineering design process into the technology education curriculum. It addressed the need for the development of a framework for understanding engineering design and the related academic concepts that can be used by professionals in the field of technology education seeking to incorporate the engineering design process into the technology education curriculum. The purpose of this study was to address the question: What are the essential aspects and related academic concepts of an engineering design process in secondary technology education curriculum for the purpose of establishing technological literacy?

#### Research Questions

1. What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?
2. What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?
3. What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?
4. What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

## Conceptual Framework

Many in the field of technology education are currently looking to engineering as a significant curriculum component (Lewis, 2004; Scarcella, 2005). In fact, at the 2005 International Technology Education Association conference in Kansas City, there were at least 23 presentations directly related to engineering in technology education (ITEA, 2005). Many believe that including engineering content will provide a method of incorporating cross-disciplinary, standards-based instruction while meeting the goal of technological literacy (Hailey et al., 2005). The literature of technology education has begun to include numerous references supporting the inclusion of engineering design in technology education. Wicklein (2006) noted that a technology education curriculum that emphasizes engineering design is valuable because

1. Engineering Design is more understood and valued than technology education by the general populace
2. Engineering Design elevates the field of technology education to higher academic and technological levels
3. Engineering Design provides a solid framework to design and organize curriculum
4. Engineering Design provides an ideal platform for integrating mathematics, science, and technology
5. Engineering provides a focused curriculum which can lead to multiple career pathways for students.

Even though there is support in the literature for including engineering content in technology education, there are many questions left to answer. Technology teachers have indicated support for the inclusion of engineering content, but also a need for additional help in developing an engineering design curriculum and teaching related concepts that have not typically been a part of technology education (Wicklein & Gattie, 2004). Evidence of the differences between engineering design and technological problem solving can be seen clearly when the two processes are compared side by side. Table 1 contains the steps normally associated with each process as found in the professional literature.

Table 1

Comparison of Engineering Design and Technology Education Design Process

Engineering Design Process (Eide, Jenison, Mashaw, & Northup, 2001)	Technology Education Design Process (Hailey et Al., 2005)
Identify the Need	Defining a Problem
Define the Problem	Brainstorming
Search for Solutions	Researching and Generating Ideas
Identify Constraints	Identifying Criteria
Specify Evaluation Criteria	Specifying Constraints
Generate Alternative Solutions	Exploring Possibilities
Analysis	Select an Approach and Develop a Design Proposal
Mathematical Predictions	Building a Model or Prototype
Optimization	Testing & Evaluating the Design
Decision	Refining the Design
Design Specifications	Communicating Results
Communication	

An obvious area of difference between the two design processes is that engineering design includes analysis, mathematical prediction, and optimization, identified as a major area of difference (Hailey et al., 2005). Dugger (1994) indicated that technology is “guided by trial and error or skilled approaches derived from the concrete,” while engineering is “guided by a more analytical study with specific solutions recommended” (p. 7). Although there are many similarities between the two processes, there are no steps in the technology education design process that correspond to the analysis, mathematical prediction, and optimization components that are an integral part of engineering design.

*Mental Processes Involved in Problem Solving*

The importance of applying the skills of analyzing and predicting in the context of solving technological problems has been identified in the literature. Halfin (1973) defined 17 mental processes technologists used in the process of solving problems. These processes were



re-examined and extended to form a list of 27 processes considered essential by a group made up primarily of engineers (Wicklein & Rojewski, 1999). A study involving factor analysis narrowed this somewhat unwieldy list down to a more accessible list of 5 areas of mental processes necessary for solving problems. A comparison of these five processes appears in Table 2.

Table 2

Mental Processes Identified by Factor Analysis

researching	managing	creating	computing	monitoring data
questions/ hypotheses	measuring	defining problem(s)	predicting	models/ prototypes
values	technology review	innovating	visualizing	Observing
establishing need	communicating	customer analysis	modeling	

*Need for Additional Research*

Technology teachers have indicated a need for additional help in gaining the requisite skills necessary in order to incorporate these aspects of engineering design. Table 3 includes partial results of a recent study (Wicklein & Gattie, 2004) on the topic of engineering design in technology education.

Table 3

Engineering Design in Technology Education Survey (n=269)

<u>My instructional needs to teach engineering design include:</u>	<u>Agree</u>	<u>Strongly Agree</u>	<u>Total Percentage Agree or Strongly Agree</u>
Integrating the appropriate levels of mathematics and science into instructional content	153	101	93.8%
Gaining the appropriate levels of mathematics and science knowledge to teach engineering design	136	96	86.3%
Developing additional analytical (math) skills to be able to predict engineering results	149	84	87.3%

In problem-solving activities using the technological method, students are not typically required to “state explicitly the theory or equations needed to solve the problem” (Oakes, Leone, & Gunn, 2002, p. 201). Often the result is that “the related mathematics [are] explored only after the problems are solved” (Cotton, 2002, p. 29) if at all. Technology educators need to develop skills from related academic areas such as mathematics and science in order to incorporate all the aspects of the engineering design process.

#### Significance of the Study

The results of this study will add to the growing literature in the field on the topic of engineering design and highlight the specific concepts from related areas (mathematics and science) that should be emphasized in secondary technology education. These concepts could then serve as a framework for creating an engineering design-focused curriculum that sustains the goals of the *Standards for Technological Literacy* (STL). One clear goal of the STL is integration of content from other areas in technology education classrooms for the purpose of understanding and managing technological systems, an ability which requires the use of concepts from science, mathematics, and other areas (ITEA, 2003). According to ITEA, “teachers [should] infuse technology programs with interdisciplinary linkages between technology and all

school subjects” (2003, p. 73). As engineering design is included in the curriculum, there will be many opportunities for “technology education to provide a role as the integrator of mathematics and science” (Hailey et al., 2005, p. 25). This study will provide a greater understanding of engineering design so that a curriculum framework can be established for a technology education curriculum with an emphasis on engineering design.

A curriculum emphasizing the mental processes technologists employ in solving problems has been suggested as a solid basis for creating a unifying curriculum framework for technology education (Wicklein & Rojewski, 1999):

The mental processes are not developed as curriculum per se; however, they may serve as a basis for creating curriculum designs that may yield comprehensive and strategic means of employing critical thinking and problem-solving strategies for students. Curriculum that emphasizes technical content tends to be rather short lived and is constantly changing due to the rapid accumulation of knowledge and techniques used in business and industry. In comparison, the mental processes and techniques used in solving technological problems could remain rather consistent over time. (p. 40)

This study will follow up and extend important research in the field on the mental processes involved in problem solving that are not typically part of the technological problem-solving process. This understanding could contribute to the creation of a framework that emphasizes the full range of mental processes involved in problem solving that have been identified in the literature and which require students to apply concepts from a range of cognitive areas.

As the concepts identified in this study are developed into a framework and infused into an engineering design-focused curriculum, a rich contextual learning environment could result. Parnell (1995) identified such a contextual learning model:

Learning for Acquisition of Knowledge. Students acquire information and retain it sufficiently to apply it toward or associate it with some real-life situation.

Learning for Application. Students are actively engaged in practicing and processing what they learn within the context of varied real-life situations, performing authentic

tasks to gain an understanding of how the information applies in everyday life.

Learning for Assimilation. Students demonstrate sufficient understanding of the content and context of what they are learning to apply knowledge and skills effectively to new situations.

Learning for Association. The educational experience is organized around problems and themes rather than subject matter disciplines; students learn to transfer acquisition, application, and assimilation of knowledge to new problem-solving situations. (p. 15)

A key component of contextual learning is providing a real-life situation in which the knowledge at hand is actually applied and students learn to associate the knowledge gained in a variety of subject areas to the problem at hand. A technology education curriculum with an engineering design focus could provide the context in which students experience the cross-disciplinary application of knowledge and skills to problems based on actual situations and events found in the world around them.

As stated earlier, the results of this study could promote the creation of a curriculum framework for technology education that would emphasize the mental processes involved in solving problems in the context of engineering design. A curriculum with this focus would occupy a justifiable position in the current era of educational accountability. Recent legislation (*No Child Left Behind, H.R.366*) has suggested that vocational programs be held accountable for helping students achieve a blend of academic and vocational goals. Therefore, technology education needs to be able to provide substantial evidence of the integration of academic content in the curriculum (Oliver, 2004; United States Department of Education, 2005). As a curriculum that emphasizes engineering design is implemented in technology education, there will be opportunities for the inclusion of concepts from math and science (Hailey et al., 2005). This increased rigor in the curriculum will be in line with current educational goals and thinking.

#### Limitations of the Study

The language of the instrument developed for this study will be clear in indicating that the study seeks to determine the proper way to implement engineering design as a component

of the curriculum in technology education rather than as a part of other content areas. This is a critical juncture, and it will be very important to make sure that each participant understands the level of specificity expected. Otherwise, the data collected could be very vague and basically meaningless.

There are some areas of uncertainty involved in the study of engineering design in technology education. It is not known whether inclusion of engineering principles involving math and science will improve student scores on standardized tests in those areas - an important consideration in the field of career and technical education. In the future, further research will need to be done in order to determine the effect that exposure to this type of curriculum would have on students' standardized test scores. Another area of research which needs to be conducted as a follow up to this study might investigate how the actual curriculum delivered in technology education classrooms should be structured and organized in order to include the engineering design content identified as important by the participants in this study.

#### Summary

In order to create a standards-based curriculum that focuses on helping all students achieve technological literacy, engineering design should be incorporated into the technology education curriculum (Dearing & Daugherty, 2004; Hailey et al., 2004; ITEA, 2000; NCETE, 2004; Wicklein, 2004). Gaining the perspective of recognized experts in the field of engineering design is important because that information could assist in the creation of a curricular framework for technology education that emphasizes the mental processes involved in problem solving in the context of engineering design. This curriculum framework could contribute to the ability of professionals in the field to select and implement rigorous curriculum components in a learning environment that emphasizes the full range of mental processes involved in solving problems.

## CHAPTER 2

### REVIEW OF LITERATURE

The history of secondary technology education in the United States is essentially a story of change. Manual training was one of the major precursors to industrial arts. In the late 1800s, John D. Runkle (then president of Massachusetts Institute of Technology) espoused a Russian system of education engineers in the practical application of their skills (Wright, 1981). He envisioned this system as a part of general education, but his views were not immediately accepted. However, another man named Calvin Woodward agreed with Runkle. He found that his engineering students were lacking in the ability to mentally picture their designs and were often without even rudimentary fabrication skills (Wright, 1981). Woodward was able to establish a program based on his beliefs. This system of study was very rigid and required that the students progress through a highly supervised course of study that included “predetermined tool exercises in wood and metal working” (Herschbach, 1982) along with academic training. Although the movement was ultimately short lived, it “was the progenitor of a progression of subjects in the US public schools curriculum which has technology as the latest version” (Lewis, 1996, p.16).

History indicates that there were many forces creating change during this time and another school of thought, originating in Europe, began to take effect: “Sloyd was a second system of hand tool education from Europe to be introduced in the United States nearly simultaneously with that of manual training” (Smith, 1981, p. 182). Sloyd activities were basic and appealed to the creative interests of children (Herschbach, 1982).

About the same time, the Arts and Crafts Movement was gaining popularity in the United States. As part of this movement, “Subjects included in the arts and crafts studies included drawing, wood carving, clay modeling, mosaic work, leather carving, metal embossing, embroidery, carpentry, wood turning, wood inlaying, and fret sawing” (Smith, 1981, p. 184).

Also in the late 1800s a man named Charles Bennett began to advocate what he termed “manual arts.” This movement primarily targeted the elementary level; the main legacy it left for the development of the field was an emphasis on “integrating drawing and design with construction activities” (Smith, 1981, p. 187). Manual training teachers were influenced by this movement to teach good design in their programs while, at the same time, attempting to foster the creative capacities of their students (Barella, 1981).

Vocationalism had a tremendous influence on manual training during this time. In the years surrounding the turn of the century, Americans were increasingly aware of the need to give students specific industrial skills in order to foster a more advanced society. As Barella (1981) notes, “Thus, the cries for secondary school vocational education that fell on deaf ears prior to 1900 began to intensify and be heard as a new century began” (p. 150) Manual training began to evolve into vocational education. Vocational education gradually displaced manual training even though many influential arguments were made for situating the study of occupations within a broader context. Dewey in particular “supported study through occupations, by all students; not just those whose probable destinies were in the trades” (Gregson, 1995, p. 7). Prosser and Snedden, on the other hand, saw vocational education as a way to prepare the masses for their future as workers in need of specific work training. They chose Taylor’s theories on scientific management as a pattern for education which was intended to serve the needs of industry (Gregson, 1995).

Those in favor of creating a vocational education that served industry began to take steps to create legislation in their favor. During this time there was a tremendous influx of students into the educational system, and new schools opened on a regular basis. Between 1900 and 1917, “more than 30 bills introduced in Congress had implications for vocational education” (Hillison, 1995, p. 4). By 1917 a diverse coalition of organizations had come together to help craft the *Smith-Hughes Act*, which effectively established a formal vocational education supported by the Federal government (Rojewski, 2001). This bill only served to exacerbate the differences between academic and vocational education that already existed (Kinchloe, 1999). This

definition was based primarily on the views of Prosser, who considered separately administered and narrowly focused vocational training the best available way to help non-academic student secure employment after completing school (Hyslop, 2000). Industrial arts gradually replaced manual training in the later stages of schooling (Lewis, 1996).

These major events shaped the creation of what came to be known as “industrial arts.” However, the debate over the focus for industrial arts continued through the years. Various curriculum development initiatives were undertaken in an attempt to further the focus and define the field. During 1946-47, William Warner and a group of his students at Ohio State University undertook a major curriculum development project which they called “A Curriculum to Reflect Technology” (Phillips, 1994). This work divided the study of industrial arts into the subcategories of communication, construction, power, transportation, and manufacturing (Phillips & Lefor, 2002). Curriculum development in the 1960s saw course development focus on these specific areas (Phillips, 1994), and Warner went on to become one of the most influential figures in industrial arts (Latimer, 1982).

Although Warner’s ideas were not immediately accepted, they did come to fruition in later federally funded projects such as the American Industry Project, The Maryland Plan, and the Industrial Arts Curriculum Project (Lewis, 1995). There were intermediate steps along the way as different groups embraced various schools of thought related to vocational education. From the 1950s through the 1970s, industrial arts programs were developed around one of three areas: 1. industry – as exemplified by the Industrial Arts Curriculum Project and the American Industry Project; 2. Technology – as promulgated by Olson and Devore; 3. The needs of the child – as found in Maley’s work (Wright, 1995).

These various curriculum approaches existed simultaneously during the 1960s and 1970s (Lauda, 2002), but a major step toward creating a unified focus for the field was the release of the Jackson’s Mill Industrial Arts Curriculum Theory (Sydner & Hales, 1981), which was a result of the Jackson’s Mill Project (Foster & Wright, 1996). Ultimately this work is associated with the acceptance of a universal systems model (input, process, output, feedback) and four



major systems: transportation, construction, manufacturing, and communication (Lauda, 2002). These became part of later technology education curriculum (ITEA, 1996). This project was an important development that was influential in conceptualization of technology education (Foster, 1994).

### Recent Technology Education Literature

The close ties between technology and engineering are reflected in the literature of technology education. Literature in the field has indicated support for including engineering content in the technology education curriculum. Bensen and Bensen (1993) stated, “it is imperative that we engage the engineering profession. The companies that employ them, the universities that educate them, and the associations and accreditation bodies that set the standards and benchmarks for them, to become involved in bringing the [technology education] curriculum into the twenty-first century” (p. 5). Foster (1996) asked selected leaders in the field to choose the most appropriate curriculum approaches in technology education. The participants in this study picked engineering systems as the fourth most appropriate approach to technology education behind the top three choices, which were math/science/technology integration, design/problem solving, and tech prep. It could be argued that three of these four top choices made by the leaders selected in Foster’s study are closely related to engineering. As Laporte observes, “Activities that integrate technology, science, and mathematics are essentially engineering activities, which are inherently laboratory based investigations with which technology teachers are quite comfortable” (1995, p. 184).

More direct evidence of the intentional inclusion of engineering content within the field of technology education comes from *The Curriculum Framework for Technology Education* published by the Georgia Department of Education (2001). This document includes course descriptions for the state-approved courses in the area of technology education. At least two of these classes are directly related to the topic of engineering, as evidenced by their titles: Pre-Engineering Technology (Course number 21.471) and Engineering Applications (Course number 21.472). The course description for Pre-Engineering Technology includes the following

statements: “This course is designed to introduce students to the concepts and practices of engineering technology and engineering careers. Students explore engineering problem solving with the integration of mathematics, science, and technology in pre-engineering activities” (Georgia Department of Education, 2001, p. 49). Clearly, the focus of this course should be the actual practices and activities of the engineering profession. The course description for Engineering Applications states that “This course is designed to address three tenets that apply to candidates for any engineering program: Students should have a well-rounded base of knowledge in as many areas of technology as possible. Students should have an area of specialized interest in which they have done extensive work. High school students should have exceptional communication skills and be able to make presentations to their peers” (Ga. DOE, 2001, p. 52). One of the key elements of the intent of this course is that candidates for engineering programs should gain skills that would benefit them in their postsecondary educational endeavors.

#### The Technology For All Americans Project

As the field of technology education has developed, significant strides have been made in achieving a unified and well-articulated curriculum focus. Perhaps the most important long-term effort directly focused on technology education has been the Technology for All Americans Project. This project has been supervised and conducted by the International Technology Education Association (ITEA), with funding from the National Science Foundation and NASA. Several major publications have been produced as a result of the efforts of this collaboration among educators at various levels as well as content experts. This endeavor was very large in scope. It emphasized the importance of technology literacy for citizens of increasing complex societies and advocated the study of technology for all children. The major publications of this project have been *Technology For All Americans: A Rationale and Structure for the Study of Technology* (ITEA, 1996), *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000), and *Advancing Excellence in Technological Literacy: Student Assessment, Professional Development, and Program Standards* (ITEA, 2003). These documents

were the major thrust of the Technology for All Americans Project and sought to provide direction and continuity to the overall effort of promoting technological literacy.

Participants in this effort were from an eclectic background including math, science, engineering, and technology education. This broad range of expertise and focus is reflected in the documents themselves; the connections between the subject areas are emphasized and the ability to apply content from various areas to real world problems is a key component of technological literacy. It is important to note that the ties between engineering, science, math, and technology were emphasized in these publications.

*Technology For All Americans: A Rationale For the Study of Technology*

The *Technology for All Americans* (ITEA, 1996) document was divided into three main parts: the need for technological literacy, the universals of technology, and integrating technology into the curriculum. The overall goal of the publication was to provide educators and administrators with a clear picture of the technologically literate person and how curriculum could reflect an emphasis on the importance of technological literacy.

The section on the Universals of Technology is particularly important to note because it affirmed the broad nature of the study of technology and provided an overall rationale on which to base future developments such as the Standards for Technological Literacy. These Universals of Technology were defined as processes, knowledge, and contexts.

The processes of technology were defined as “those actions that people undertake to create, invent, design, transform, produce, control, maintain, and use products or systems. The processes include the human activities of designing and developing technological systems; determining and controlling the behavior of technological systems; utilizing technological systems; and assessing the impacts and consequences of technological systems” (ITEA, 1996, p. 17). A key aspect of technological literacy is the ability to design and develop technological systems “through experiences in designing, modeling, testing, troubleshooting, observing, analyzing, and investigating” (p. 18). This emphasis on designing technological systems was an

intentional effort to make sure that the proper understanding of technological literacy included not only information about technology and technological devices, but abilities to creatively solve problems using a systems approach.

Another aspect of the processes of technology is the ability to determine and control the behavior of systems. A proper understanding of a system should allow the technologically literate person to adjust and control the overall function to achieve the desired output or result: “Analysis is required in order to determine how many systems work. Analysis often uses information from science and mathematics” in the process of solving problems (ITEA, 1996, p. 19). A technologically literate person is able to make use of knowledge and skills from other disciplines when dealing with the behavior of systems.

The second universal of technology was defined as knowledge. This “includes the nature and evolution of technology; linkages based on impacts, consequences, resources, and other fields; and technological concepts and principles” (ITEA, 1996, p. 16). The technologically literate person should recognize that technological systems are developed and understood in the context of knowledge from other disciplines and that “technology has a particularly strong relationship with science and mathematics” (ITEA, 1996, p. 28). Technology, mathematics, and science are interrelated and dependent on each other. Technological literacy emphasizes the importance of these relationships and makes use of knowledge from each of these disciplines.

After providing this framework, *Technology for All Americans* (ITEA, 1996) discussed teaching technology at various educational levels. After discussing the elementary and middle school levels, it included an important section on teaching technology at the high school level and beyond:

Technology Education students should evaluate technology’s capabilities, uses and consequences on individuals, society, and the environment, employ the resources of technology to analyze the behavior of technological systems, apply design concepts to solve problems and extend human capability, apply scientific principles, engineering

concepts, and technological systems in the solution of everyday problems, and develop personal abilities related to careers in technology. (ITEA, 1996, p. 40)

Also, these activities should be carried out in the context of specific technology courses such as Introduction to Engineering (ITEA, 1996, p. 40). Clearly, this document intended to embrace the field of engineering and make it an important part of technological literacy for students.

### *Standards for Technological Literacy*

The Technology for All Americans Project also produced the *Standards for Technological Literacy* (ITEA, 2000). This important publication built on earlier work related to technological literacy. The purpose was to provide “a vision of what students should know and be able to do in order to be technologically literate” (ITEA, 2000, p. 7). This vision was articulated in the form of twenty content standards that outlined basic curricular goals for technology education at the K-2, 3-5, 6-8, and 9-12 grade levels. These standards were intended to shape the curriculum of technology education in order to help students achieve technological literacy. The standards “are statements about what is valued and can be used for making a judgment of quality” (ITEA, 2003, p. 7) regarding the curriculum chosen for technology education programs. The Standards for Technological Literacy are divided into five sections: (1) The Nature of Technology, (2) Technology and Society, (3) Design, (4) Abilities for a Technological World, and (5) The Designed World (ITEA, 2003). These broad categories help to define the criteria that make up technological literacy.

Several of the standards have direct application to this study and are included here:

Standard 8: Students will develop an understanding of design;

Standard 9: Students will develop an understanding of engineering design;

Standard 11: Students will develop the ability to apply the design process (ITEA, 2000).

The clear argument of this publication is that activities in technology education are intended to teach skills necessary in professions such as engineering. Lewis (2000) indicated that the design called for in the STL is actually the same process employed by engineers when they solve problems:

Students in technology laboratory-classrooms are taught practical problem solving skills and are asked to put them to work on different types of real-world problems. Engineers, architects, computer scientists, technicians, and others involved in technology use a variety of approaches to problem solving, including trouble shooting, research and development, invention, innovation, and experimentation. Students will become familiar with these approaches and learn about the appropriate situations in which to use them. (ITEA, 2000, p. 5)

In explaining Standard 8, the document gives further detail about the design process by stating “the engineering profession has developed well-tested sets of rules and design principles that provide a systematic approach to design. Design measurability, which is a key concept of the engineering profession today, is concerned with a designer’s ability to quantify the design process in order to improve the efficiency” of the system (ITEA, 2000, p. 91). The emphasis is on creating situations within the K-12 environment in which students have the opportunity to gain real-world skills such as “performing measurements, making estimates and doing calculations using a variety of tools, working with two-and three-dimensional models, presenting complex ideas clearly, and devising workable solutions to problems” (ITEA, 2000, p. 90).

The ninth standard deals with engineering design specifically. While recognizing that the field of engineering has not come to a consensus on a single definition of what actually happens in engineering design, it is clear that students should be familiar with: identifying the problem, generating ideas, selecting possible solutions, evaluating solutions (often through models and prototypes), and refining solutions, and implementing the solution (ITEA, 2000, p. 99). This standard calls for a broad understanding of the nature of engineering design and the many factors that go into the process such as “safety, reliability, economic considerations, quality control, environmental concerns, manufacturability, maintenance and repair, and human factors engineering (ergonomics)” (ITEA, 2000, p. 105). The process also involves personal characteristics that should be emphasized by educators “such as creativity, resourcefulness, and the ability to visualize and think abstractly” (p. 104).

The eleventh standard deals with students' ability to apply the design process. This process is responsible for the development of most technologies: "Very few products or systems today are developed by trial and error or come by accident. Instead, almost any technology that a student encounters is the result of a "systematic problem-solving design process that transformed an idea into a final product or system" (ITEA, 2000, p. 115). This publication emphasizes the importance of understanding the various components of design so that students can give clear explanation of the choices made in reaching solutions to design problems. Secondary students should be given challenging problems that require a synthesis of knowledge from various disciplines so that they achieve the greatest level of learning possible. Students should be required to

Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product. Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed. Develop and produce a product or system using a design process. Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models. (p. 124)

Applying the design process is a crucial juncture in achieving technological literacy because it is here that students need to have the ability to draw upon principles from other disciplines in the creation, evaluation, and analysis of their designs. Specifically, students should be required to explain their decisions using verbal and quantitative skills transferred from language arts and mathematics. The solutions to technological problems that students design should also be based on basic scientific principles that can be reinforced in the technology education classroom and applied in the design process.

Gorham (2002) noted distinct similarities between criteria selected by the Accreditation Board for Engineering and Technology (ABET) and the Standards for Technological Literacy. The ABET "is widely recognized as the agency responsible for accrediting educational programs

leading to degrees in engineering” (Gorham, 2002, p. 30). Included below are the eleven criteria selected by this agency as mandatory for all engineering preparatory programs. It is especially important to note the similarities to the goals and standards for technological literacy:

Criterion A: Ability to apply knowledge of mathematics, science, and engineering

Criterion B: Ability to design and conduct experiments, as well as to analyze and interpret data

Criterion C: Ability to design a system, component, or process to meet desired needs

Criterion D: Ability to function on multi-disciplinary teams

Criterion E: Ability to identify, formulate, and solve engineering problems

Criterion F: Understanding of professional and ethical responsibility

Criterion G: Ability to communicate effectively

Criterion H: Broad education necessary to understand the impact of engineering solutions in a global and societal context

Criterion I: Recognition of the need for and an ability to engage in lifelong learning

Criterion J: Knowledge of contemporary issues

Criterion K: Ability to use techniques, skills, and modern engineering tools necessary for engineering practice (ABET, 2005, p.6)

Gorham (2002) displayed similarities between the Standards for Technology Literacy (STL) and the ABET criteria. Each of the 11 criteria selected by ABET were matched to corresponding standards and the results showed extremely strong correlations. Ten of the eleven ABET criteria were matched to at least one of the STL standards with most having correlation to multiple standards. Gorham concluded that “as school districts adopt and implement Standards for Technological Literacy, increased numbers of pre-college students will be exposed to the breadth of engineering” (p. 30).



*Advancing Excellence in Technological Literacy: Student Assessment, Professional Development, and Program Standards*

In 2003, the International Technology Education Association published a follow up document called *Advancing Excellence in Technological Literacy: Student Assessment, Professional Development, and Program Standards* (ITEA, 2003). This was also part of the Technology for All Americans Project. Its goal was to further explain how teachers, administrators, and others could participate in the goal of technological literacy for all students. This publication, also referred to as AETL, sought to reinforce the groundwork established by the *Standards for Technological Literacy* and broaden the perspective to include administrators and others in positions to make decisions about technology education programs.

It is important to note that AETL also included references to the close ties that exist between technology and other fields such as mathematics, science, and engineering. It also encourages teachers to help students understand these connections and to make use of subject matter from these disciplines in the study of technology. In addition, teachers “may require students to identify technological problems, needs, and opportunities within a cultural context; write and construct problem statements; design, develop, model, test, prototype and implement solutions; analyze, evaluate, refine, and redesign solutions; and reflect and assign value to processes and outcomes” (ITEA, 2003, p. 31). Solving problems in this context calls for a broad understanding of the problem-solving process and the use of information and skills from a variety of sources.

One of the goals of AETL is to help teachers understand how to assess students as teachers develop technological literacy. Various methods of formative and summative assessment are discussed. Standard A-4 makes it evident that assessment should occur in the context of how students actually learn technology rather than only traditional methods of pencil and paper testing. Assessment should be an informative process; it should allow the teacher to truly gauge the students’ understanding of the content and should include multiple means that are all authentic. Part of this authentic assessment should involve tasks that require students to “use

appropriate technology, science, and mathematic principles” (ITEA, 2003, p. 32) in their projects so that the level of technological literacy can be demonstrated. The AETL emphasizes the role of engineering design in technology education:

There are strong philosophical connections between the disciplines of technology and engineering. The engineering profession has begun to work with technology teachers to develop alliances for infusing engineering concepts into K-12 education. The alliances will provide a mechanism for greater appreciation and understanding of engineering and technology. The National Academy of Engineering is as avid supporter of technological literacy. (p. 13)

In order for teachers to be able to adequately teach and assess learning in this context, the AETL document provides standards related to professional development detailing the skills educators need. Teachers should be constantly learning and enhancing their knowledge of technology and its relationship to math, science, and engineering (ITEA, 2003) in order to help students achieve technological literacy. Part of the strategy for accomplishing this goal is for teachers to know the process of design and to be “acquainted with engineering design” (ITEA, 2003, p. 42) as well as other problem-solving strategies.

#### Related Literature

*Technically Speaking: Why All Americans Need to Know More About Technology*

These documents from the Technology for All Americans Project are catalysts in achieving technological literacy. Another very important recent publication has been a joint publication from the National Academy of Engineering and the National Research Council titled *Technically Speaking: Why All Americans Need to Know More About Technology* (Pearson & Young, 2002). This publication was a direct result of a two-year effort by the Committee on Technological Literacy, which operated under the direction of the National Academy of Engineering. The dominant theme of the text is achieving technological literacy in our country through a variety of formal and informal means. This publication discussed the major reasons for focusing on technological literacy, the benefits students would receive, the proper context,

and the philosophical foundation underlying this initiative. Does this include a call for the study of engineering design? Engineering design is given an important place in technological literacy and even state that the one of the characteristics of a technologically literate person is that such a person is “familiar with the nature and limitations of the engineering design process” (Pearson & Young, 2002, p. 17). Technological literacy is viewed as a requirement for all students and a national concern that merits the best efforts of all those having influence over formal and informal educational settings. Pearson and Young discuss the lack of emphasis education about technology has received in recent years and also ways to overcome these deficiencies.

*Technically Speaking* also directly addresses those who teach technology and recommends that technology teachers “approach the subject from an engineering perspective rather than an industrial arts perspective” (Pearson & Young, 2002, p. 108). Technology educators are encouraged to become familiar with the interrelationship between technology and other subjects, especially science and math, and to help other teachers integrate the study of technology into their curriculum. The design process plays a prominent role in the instructional strategies recommended by *Technically Speaking*. According to a recent work, “teachers at all levels should be able to conduct design projects and use design-oriented teaching strategies to encourage learning”(Pearson & Young, 2002, p. 108).

For all the indicators pointing to the inclusion of engineering content in the technology education curriculum, there is actually a lack of research on how to go about this process. In a recent survey of high school technology education teachers, Wicklein and Gattie (2004) found that the 279 respondents had a generally positive view of the value of engineering design for technology education. In fact, an average of 90.6% of the survey respondents indicated agreement or strong agreement with the fourteen statements on the benefits of including engineering design in the technology education curriculum. Although the survey indicated consistently positive responses regarding the perceived value of engineering, there was also agreement on the need for additional assistance in developing an appropriate curriculum. The

following percentages reflect the number of those who either indicated agreement or strong agreement with the statements:

*My instructional needs to teach engineering design include:*

identifying appropriate instructional content (91.4%), determining the appropriate level of instruction (89.7%), integrating the appropriate levels of mathematics and science into the instructional content (93.8%), having the appropriate types of tools and test equipment to teach engineering design (93%), developing additional analytic (math) skills to be able to predict engineering results (87.3%), improving fundamental knowledge of engineering sciences (statics, fluid mechanics, dynamics) (91.9%).

### Engineering Design

Engineering has been called “a fundamental human process that has been practiced from the earliest days of civilization” (Petroski, 1996, p. 2). From ancient times men have endeavored to use tools and processes to meet their needs and to make life more tolerable. Human need served as the catalyst for the application of knowledge and resources to the problem at hand. The word “engineer” can be traced to Roman times “when the Latin expression *ingenium* was used to suggest some ingenious attribute of an object or a person. Eventually, the derivative *ingeniator* was applied to a person possessing an innovative mind and skillful hands in the making of such devices” or products (Harms et al., 2004, p. 3). Over time, the methods used to solve problems and make ingenious devices coalesced into a series of steps that have come to be known as the engineering design process. Engineering literature defines and explains this process, although there is some debate about the exact nature of the process and the exact steps involved.

Some of the definitions of engineering design in the literature are succinct and extremely broad: “Engineering design is a systematic process by which solutions to the needs of humankind are obtained” (Eide et al., 2002, p. 79). Another one is “Engineering design is the systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints” (Dym, 1994, p. 17). This process has been described as being “as varied as the engineering profession, and it is as broad as the

problems facing humankind” (Wright, 2002, p. 111). Other definitions are more complete and describe this process in greater depth:

The accreditation board for Engineering and Technology (ABET) has traditionally defined engineering design as follows: Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision making process in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. It is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact. (Oakes et al., 2002, p. 339)

In addition to these definitions, the engineering design process is usually thought of as a series of steps. Various authors have defined the steps differently. Wright identified the following steps:

1. Identification of the problem
2. Gathering needed information
3. Searching for creative solutions
4. Stepping from ideation to preliminary designs (including modeling)
5. Evaluation and selection of preferred solution
6. Preparation of reports, plans, and specifications
7. Implementation of the design (Wright, 2002, p. 113)

These basic steps are repeated in the literature of engineering (with variations) and are generally typical of the descriptions given. Some descriptions include more steps because of greater detail in their explanation or because of breaking some parts into more than one step. One example of this situation is the ten-step design process (Eide et al., 2002, p. 81):

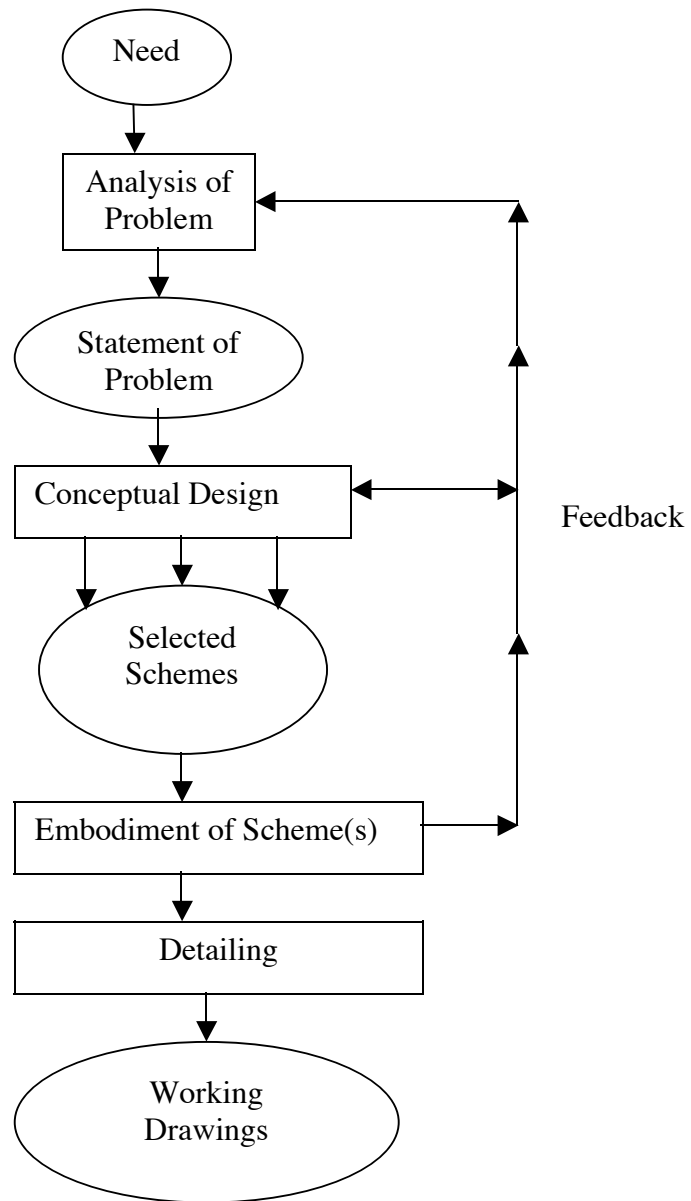
1. Identification of need
2. Problem definition
3. Search

4. Constraints
5. Criteria
6. Alternative Solutions
7. Analysis
8. Decision
9. Specifications
10. Communication

This process is sometimes depicted as a circle or a repeating cycle in order to emphasize the iterative nature of the process and to reinforce the concept of continual improvement of possible solutions. French (1992) described the process in a flow chart (see Figure 1) that provides greater detail on the order of the steps and iterative nature of the design process.

Figure 1

French's design process diagram



An engineering curriculum developed by the Massachusetts Department of Education describes the engineering design process as follows:

1. Identify the need or problem
2. Research the need or problem
  - Examine current state of the issue and current solutions
  - Explore other options via the Internet, library, interviews, etc.
3. Develop possible solution(s)
  - Brainstorm possible solutions
  - Draw on mathematics and science
  - Articulate the possible solutions in two and three dimensions
  - Refine the possible solutions
4. Select the best possible solution(s)
  - Determine which solution(s) best meet(s) the original requirements
5. Construct a prototype
  - Model the selected solution(s) in two and three dimensions
6. Test and evaluate the solution(s)
  - Does it work?
  - Does it meet the original design constraints?
7. Communicate the solution(s)
  - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
  - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
  - Overhaul the solution(s) based on information gathered during the tests and presentation (Massachusetts DOE, 2001)

Regardless of the actual set of steps chosen or the graphic model used to depict the various aspects of the design process, there are certain tasks common to the engineering design



process known as synthesis, analysis, and evaluation. These tasks are repeated at various stages in the process. Dym (1994) says that “Synthesis is the task of assembling a set of primitive design elements or partial designs into one or more configurations that clearly and obviously satisfy a few key objectives and constraints. Synthesis is often considered as the task most emblematic of the design process”(p. 28). As the term implies, the task of synthesis frequently “involves combining facts, principles, or laws into a whole idea” (Wright, 2002, p. 118). Synthesis in engineering includes the concept of relating ideas to one another in such a way as to create a solution to a problem based on the interrelationship of the various parts in a systematic solution (Buhl, 1960).

Another task central to engineering design is analysis. In the process of analysis, engineers “break down accumulated information to determine, item by item, its contribution to the whole problem” (Buhl, 1960, p. 76). The goal is to determine the characteristics and resulting influence of each individual component of a possible solution. Analysis allows engineers to “work with the governing equations and relationships” (Burghardt, 1999, p. 75) that are necessary for a true understanding of the problem at hand. Dym notes that “Analysis is the task of performing those calculations (or analyses) needed to assess the behavior of the current synthesis – or embodiment or preliminary design” (1994, p. 28).

The third task associated with engineering design is the evaluation task. This task occurs when “we compare our analyses of the attributes and behavior of the current design to the stated design specifications and constraints to see if this synthesis is acceptable” (Dym, 1994, p. 28). In other words, the task questions the appropriateness of the solution obtained by analysis.

#### Accountability

In the current era of educational reform, career and technical education is being held responsible for providing programs that enable students to reach academic accountability. Student success is currently one of the requirements being asked of all programs, including career and technical education (Green, Stacey, & Tulley, 2005). Current legislation affecting CTE has continued the trend toward a emphasis on academic achievement for all students:

In the decade of the 1990s, the federal government passed three laws that were intended to, among other outcomes; improve the academic performance of high school youth who “majored” in CTE. The *Carl D. Perkins Vocational and Applied Technology Education Act of 1984* revisions in 1990 (Perkins II) and 1998 (Perkins III) reflected a philosophical shift in the goal of vocational education (or CTE), from a narrow focus on occupational preparation for special populations to a more academically rigorous program that prepared students for participation in industry as well as for postsecondary education. (Stone, 2004, p.53)

Secondary level technology education programs exist in the larger educational setting of career and technical education. Hoachlander (1998) noted that a curriculum framework reflective of the current state of career and technical education should “help strengthen the academic foundation of secondary and postsecondary education by helping students learn and apply a wide range of academics in a work-related context” (p. 4). As Delci and Stern (1999) have commented,

Conflicting crosscurrents have flowed through vocational education in American secondary schools during the 1980s and 1990s. Overall enrollment in vocational courses has fallen. But against this ebbing tide, an incoming current has brought a growing number of participants into new programs and curricula. While traditional vocational offerings have been geared toward immediate entry into specific occupations, new programs and course sequences are intended to prepare students for both college and careers, by combining a challenging academic curriculum with development of work-related knowledge and skill. (p. 9)

Stone (2004) found that CTE students were taking a more rigorous academic content. This has been demonstrated by the increased number and difficulty of the math courses taken.

#### Mental Processes

Custer (1995) distinguished between technological problem solving and other forms of solving problems. Technological problem solving has been identified as the major element involved in the processes of technology that have been identified in the literature of technology

education (Hill & Wicklein, 1999). Technological problem solving relies on mental processes identified by Halfin (1973). Halfin’s doctoral study identified 17 mental processes (see Table 4).

Table 4

Mental Processes Identified by Halfin

Analyzing Communicating Computing Creating Defining problem(s) Designing Experimenting Interpreting data Managing	Measuring Modeling Models/prototypes Observing Predicting Questions/hypotheses Testing Visualizing
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Wicklein and Rojewski (1998) reaffirmed Halfin’s original mental processes and extended the list to include several additional processes considered vital to the solving of technological problems (see Table 5).

Table 5

Mental Processes Identified by Delphi

Analyzing Communicating Computing Contexts Creating Customer Analysis Defining Problem(s) Designing Establishing Need Experimenting Innovating Interpreting Data Managing Measuring	Modeling Models/Prototypes Monitoring Data Observing Predicting Questions/Hypotheses Researching Searching for Solutions Technology Review Testing Transfer/Transformation Values Visualizing
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This list of processes was condensed into a more manageable list of key constructs (Hill & Wicklein, 1999) associated with technological problem solving (see Table 6).

Table 6

Mental Processes Identified by Factor Analysis (Hill & Wickein, 1999).

researching	managing	creating	computing	monitoring data
questions/ hypotheses	measuring	defining problem(s)	predicting	models/ prototypes
values	technology review	innovating	visualizing	observing
establishing need	communicating	customer analysis	modeling	

## CHAPTER 3

### METHOD

This chapter provides a description of the research design, sample, instrument, and procedures that will be used to conduct this study. In addition, this section contains a discussion of how data was analyzed.

#### Research Design

This study relied on input from experts in the field of engineering regarding the nature of the engineering design process and how it should be taught to secondary students enrolled in Technology Education classes. An expert is “a person who has background in the subject area and is recognized by his peers or those conducting the study as qualified to answer questions” (Meyers & Booker, 1990, p. 3). Expert judgment is frequently used to make predictions about future events and has been defined as “the assertion of a conclusion based on evidence or an expectation for the future, derived from information and logic by an individual who has extraordinary familiarity with the subject at hand” (Millet & Honton, 1991, p. 43). Meyers and Booker (1990) identified several situations when expert judgment is typically gathered:

- To provide estimates on new, rare, complex, or otherwise poorly understood phenomena
- To forecast future events
- To integrate or interpret existing data
- To learn an expert’s problem-solving process or a group’s decision making processes
- To determine what is currently known, what is not known, and what is worth learning in a field of knowledge. (pp. 4-5)

Research that makes use of the judgment of a panel or group of experts has been shown to be valuable and accurate (Brown & Helmer, 1964). One reason for this outcome is that “the total

information available to the group is probably many times that possessed by any single member” (Martino, 1983, p. 14).

Expert judgment is frequently gathered in a form that is quantitative in nature (Bookers & Meyers, 1990). This data can be considered to be formal and “involves selecting experts according to particular criteria, designing elicitation methods, and specifying the mode in which the expert is to respond” (Meyers & Booker, 1990, p. 6). This study used the Delphi method because it allows experts to have input on the topic of this study in a very efficient manner. The basic idea of the Delphi procedure is “repeated administration of questionnaires to each member of an expert panel, without face-to-face contact” (Dean & West, 1999, p. 4).

The original development of this method has been attributed to a Rand Corporation study for the United States military in the 1950s (Dalkey & Helmer, 1963), and it has come to be a common research methodology in various fields, especially when consensus on a topic is desired (Borg & Gall, 2003). The Delphi method has been noted as an effective means of facilitating a group decision process on a complex subject or problem (Linstone & Murray, 1975). This method of research is extremely flexible and lends itself to a broad range of applications. The Delphi method has been described as “a method of eliciting and refining group judgments” (Dalkey, 1969, p. 5). The Delphi method has distinct advantages that are documented in the literature:

1. The consensus reflects reasoned, self-aware opinions, expressed in the light of the opinions of associate experts. Thus, these predictions should provide a sounder basis for long-range decision making than do unarticulated intuitive judgments.
2. Research suggests that face-to-face discussion tends to make the group estimates less accurate, whereas the controlled-feedback procedure makes group estimates more accurate.
3. The procedures create a well-defined process that can be described quantitatively.

4. A meaningful estimate of the accuracy of a group response to a given question can be obtained by combining individual self-ratings on that question into a group rating. (Lanford, 1972, p. 22)

There are three important features of the Delphi method that are useful for this study: anonymous response, iteration and controlled feedback, and statistical group response (Dalkey, 1969):

1. Anonymous response – opinions of the group are obtained by formal questionnaire.
2. Iteration and controlled feedback – interaction is effected by a systematic exercise conducted in several iterations, with careful, controlled feedback between rounds.
3. Statistical group response – the group opinion is defined as an appropriate aggregate of individual opinions on the final round. These features are designed to minimize the biasing effects of dominant individuals, of irrelevant communications, and group pressure toward conformity. (p. 5).

Anonymous response is important to allow individuals to freely express their true opinions on matters related to the subject at hand. Anonymity is also important because individuals of higher status may exert too great an influence on other group members. Also, group members who perceive of themselves as lower in status may tend to be hesitant to offer their ideas (Turoff & Hiltz, 2005). Dalkey (1969) found that anonymous response had a tendency to make the overall assessment more accurate.

The fact that the study has iterations with controlled feedback is extremely important because this approach helps facilitate and clarify all communication; the experts involved in the study will have the opportunity to receive feedback on the responses given by other members of the group and then to clarify or add to their original answer in the second iteration of the study. The ability to achieve a true statistical group response is also very important and minimizes the chance of having a committee swayed inordinately by a few dominant personalities (Turoff & Hiltz, 2005).

There are typically several rounds or iterations involved in a Delphi study. As the iterations proceed, there is a general trend toward a greater understanding of the questions involved and group consensus (Dalkey, 1969). It is important to note that complete agreement on all parts of the problem is not considered a realistic goal and should not be expected by researchers. In general, the questionnaires become more specific and focused in later iterations because they contain feedback for the participants regarding the groups' responses to earlier questions.

### Population and Sample

An initial group of engineering design experts was identified through contact with Dr. Clive Dym, director of the Engineering Design Center at Harvey Mudd College, Claremont, California. Dr. Dym is an internationally recognized expert on engineering design issues and has organized and conducted engineering design conferences for the past nine years. These conferences typically are attended by internationally recognized experts in engineering design. In April of 2006, Dr. Dym was asked (see Appendix A) to identify a panel of 10 persons whom he considered to be experts in engineering design who could serve as participants in this study. Dr. Dym actually identified 12 persons whom he considered to be highly qualified. The 12 people thus identified were contacted through email and asked to identify 10 leading experts in engineering design each. Ten of the original list of 12 agreed to supply names and generated a pool of 59 names. This was a somewhat shorter list than hoped for and due to time constraints it was decided to invite each of these persons on this list to participate in the study.

At this point, this study began to utilize the services of the [Hostedsurvey.com](http://Hostedsurvey.com) website. This service was utilized to make initial contact with the potential participants, send reminder emails, and conduct each round of the study. With the vast capabilities of the Internet, research conducted online has become increasingly popular (Wong, 2003). Typically, "the Internet is used as the medium and the exercise and the material are generally posted on a Web site. Participants will log onto the Web site during a specific period (e.g., a week) and provide inputs at times



compatible with their individual schedules” (p. 18). Participants accessed the survey website to view each questionnaire and responded with either a written message or a numerical response as the question dictated. Participants had a window of time (10 days) in which to complete the current round. On the day the current survey became available online, an email was sent to let participants know what set amount of time was available in which to access the website and answer the questionnaire.

During May and June of 2006 contact was made with each of the 59 potential participants through email and also through telephone calls when necessary. The initial email (see Appendix B) described the study and also contained a link to the website that collected simple demographic data and consent to participate in the four-round Delphi study. The number of participants desired was 25 because this number would leave room for the possible attrition of some members of the panel during the study due to circumstances beyond their control (Martino, 1983). Table 7 contains the timeline of the study.

Table 7

Study Timeline for 2006 (Deadline to join the study - June 16)

<u>Round #</u>	<u>Date</u>
Round 1	June 19 - 28
Round 2	July 10 - 19
Round 3	July 24 – August 2
Round 4	August 7 - 16

By the June 16, 2006 deadline, 22 people had indicated their willingness to participate in the study. Many had to be reminded of this deadline, and dozens of calls were made to the potential participants who had not responded to the initial email invitation. Of the 22 people who agreed to participate, 21 accessed the website to indicate their agreement, and one person gave verbal consent.

## Round 1

After the initial deadline to join the study, an email was sent out to all who had agreed to participate (hereafter called “participants”). This email contained some brief instructions and also a hyperlink which allowed access to the study website (see Appendix C). Participants were asked to provide 7-10 phrases or short answers to the four research questions:

1. What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?
2. What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?
3. What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?
4. What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

This was a very crucial stage because it was imperative that all participants understood the questions correctly so that their responses would be applicable to the research goals of the study.

A reminder email was sent out three days before the end of Round 1, and telephone calls were made to solicit responses. A total of 15 out of the 22 original participants completed the Round 1 survey by the deadline of June 28, 2006. Two hundred and thirty-four total responses to the four research questions were recorded (see Appendix D).

After the close of Round 1 on June 28, 2006, it was necessary to conduct a review of the data to establish a valid list of all unique responses to the four research questions. Outside reviewers were identified by contacting Dr. Kurt Becker at Utah State University and asking him to recommend reviewers. Dr. Becker recommended Dr. Paul Schrueders, who in turn recommended Dr. Tim Taylor. Consequently, the raw data from Round 1 was compiled and sent to Drs. Schrueders and Taylor, both of whom are members of the engineering faculty at Utah State University. Dr. Schrueders is in the Department of Engineering and Technology Education,

while Dr. Taylor is a member of the Department of Biological and Irrigation Engineering. These men agreed to review the raw Round 1 data and create a list of all unique responses to each of the four research questions. The data was sent to them on June 29, 2006. The Round 1 data was compiled into a list of 88 unique responses and are identified in Table 13 of Chapter Four.

### Round 2

The review completed by Drs. Schrueders and Taylor allowed the creation of the Round 2 survey based on their assessment of the Round 1 data. The Round 2 survey (see Appendix E) was made available to participants July 10, 2006. On that day an email was sent out to each of the 15 persons who had completed the Round 1 survey, informing them that the survey was available and would be open until July 19, 2006. Each unique response identified from the Round 1 data by Drs. Schrueders and Taylor was included in the Round 2 survey. Each item was listed along with a 6-point Likert scale (see Table 8) which allowed the participants to indicate their level of agreement or disagreement with each statement.

Table 8

#### Likert Scale

Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6

In addition, participants were asked if there were any additional items that they wished to add to the list of responses from Round 1. Participants were free to add any additional items at this point that they felt helped to answer the research questions.

On July 16, 2006 a reminder email was sent out to all participants who had not completed the Round 2 survey. In addition, telephone calls were made to those who had not responded to the email invitation or subsequent reminder. This process resulted in 13 responses to the Round 2 survey by the July 19, 2006 deadline.

A statistical analysis of the responses in Round 2 resulted in an empirical measure of the level of support afforded each individual response by the group. The data from Round 2 was analyzed using descriptive statistics, and the mean, maximum, minimum, standard deviation, and interquartile range were calculated. The most important statistic involved in a Delphi study is the median response to each item (Dalkey, 1968) because this outcome most accurately describes the overall rating of the particular item. The mean, standard deviation, and interquartile range were also used to report on the group response to the various items generated by the participants. The interquartile range is a common statistical measure denoting the distance between the 75th and 25th percentiles. The interquartile range is the middle 50% of the responses to an individual item and was the primary measure of the degree of consensus achieved. A common measure of the interquartile range that indicated an acceptable level of agreement has been identified as less than 1.2 (Custer, Scarcella, & Stewart, 1999). For the purposes of this study, the interquartile range that indicated a high level of consensus was a score that was  $\leq 1$ . A range of one (1) or less indicated that the middle 50% of responses were either identical (IQR=0) or sequential (IQR=1). Helmer (1983) noted that the greatest degree of convergence of expert opinion in Delphi studies generally occurs between Rounds 1 and 2.

### Round 3

The Round 3 survey (see Appendix G) included all the previous rounds plus additional items suggested by participants in Round 2. Items brought forward from Round 1 thus had numeric scores associated with them that had been analyzed as mentioned previously but the few new items identified did not. The Round 3 survey was prepared so that the Round 2 statistical data for each individual item (except the new ones identified in Round 2) was displayed beside the item along with the six-point Likert scale. This presentation was important because each participant could compare his own Round 2 score with the group's scores. The purpose in Round 3 was to allow the experts to see how others in the sample group responded in Round 2 and to give them a chance to revise their own responses in light of the group response to the same items.

The survey included space for participants to add comments on any of their answers that fell outside the interquartile range. As in the Round 2 survey, participants also had the opportunity to add any new items if they wished.

On July 24, 2006 an email was sent to the 13 participants who had completed the Round 2 survey, informing them that the survey was available and asking them to finalize their responses by August 2, 2006. On July 31 a reminder email was sent out and additional telephone calls were made to remind participants to complete and submit the survey. A total of 13 surveys were submitted by the August 2 deadline.

#### Round 4

The Round 3 data was analyzed using the descriptive statistics mentioned previously. Some Round 3 items were omitted from Round 4 because they met the criteria for stability and consensus during the first three rounds. The literature finds that the vast majority of participants have been found to reach their final conclusions by the third round (Cyphert & Gant, 1971; Martino, 1983) and that three rounds are typically enough for the study to reach stability (Linstone & Turoff, 1975). The degree of stability was gauged by determining the percentage of mean change between rounds for each response. Items that had a less than 15% overall change in mean score between rounds two and three were considered stable (Scheibe et al., 1975). Stability of the experts' responses is one of the major indications of the validity of the results (Dalkey, 1969).

A second consideration at this point was the level of consensus each item had achieved. The same parameter described previously ( $IQR \leq 1$ ) was used to determine whether participants had reached consensus or not. A large percentage of items from Round 3 had achieved stability by this definition.

The third consideration for inclusion in Round 4 was whether an item had any comments from Round 3. A very small number of comments were made defending the score given an item in any of the rounds and these were included in subsequent rounds so that all participants were aware of the discussion. In addition to the above conditions, there were a few additional items

added in Round 3 that were added to the Round 4 survey. They had no statistical data associated with them since they were new. Items that were included in the Round 4 survey (see Appendix I) had the results from Round 3 listed beside them along with the 6-point Likert scale. Any comments submitted in Round 3 were also included with the appropriate item so that it was available to all participants.

### Summary

This study sought to contribute to the development of an understanding of engineering design within technology education. This is an important and timely topic because of the recent emphasis on engineering and engineering design in the literature of technology education. The Delphi method has been identified as an appropriate means of creating a dialogue among professionals and making informed decisions based on the expert judgment of persons with a great degree of knowledge in a particular field (Meyer & Booker, 1990). Participants in this study were identified as experts in the field of engineering design by their peers through a process that is logical and repeatable. Twenty-two participants were selected from a list of 59 persons considered to be highly knowledgeable in the area of engineering design.

This study utilized four rounds to give multiple opportunities for the group opinion to coalesce. Each round of the study was conducted via the Internet and participants accessed the questionnaires at a website dedicated to this study. Participants had a set amount of time in which to record their answers on the web-based questionnaires that utilized Likert scales. Descriptive statistics were used to report the group responses and to ascertain the degree of stability for each item. The panel of experts anonymously participated in the study. All items in the study will be included in the final report, whether or not they achieved consensus and stability.

## CHAPTER 4

### RESULTS

A four-round Delphi research process was used to elicit the responses of experts to four open-ended research questions related to engineering design in technology education. Fifty-nine possible participants were identified by a panel of 12 engineering design experts who had been recommended by Dr. Clive Dym. Twenty-two (22) of the 59 persons agreed to participate in the study although only 15 actually completed the Round One survey instrument. Table 9 displays the actual number of those completing each survey for each of the four rounds of the Delphi research process.

Table 9

Completers by Round

<u>Round #</u>	<u>Number</u>
Round 1	N=15
Round 2	N=13
Round 3	N=13
Round 4	N=12

Table 10 displays the demographic data of the participants who completed the Round One survey instrument.

Table 10

Demographic Data for Round One Participants: N=15

<u>Gender</u>	<u>Average years of experience</u>	<u>Highest level of education</u>	<u>Area of expertise</u>	<u>Current employment</u>
Male n=14	23.4	Ph.D. n=13	Mechanical Engineering n=12	University n=14
Female n=1		Post-doctoral n=2	Design n=1	Industry n=1
			Mechanical and Industrial Engineering n=1	
			Design Methodology n=1	

The study was conducted via the Internet and participants completed and submitted all survey instruments electronically. Data from previous completers was retained in subsequent rounds even if they did not complete additional surveys (Ludlow, 2002) because this input can be considered important and valid even if the participant does not complete subsequent rounds.

It is important to note that each of the participants completing all rounds in this Delphi research process had a background in mechanical engineering. They were also all employed in academic settings except for one. This commonality among participants provides strength and focus for the study in that it is easy to categorize the results of this study and compare them to the results of other studies with similarly homogenous groups. Based on personal correspondence with Dr. David Gattie at UGA (November 11, 2006), this mechanical engineering focus does provide some possible areas of bias, especially in the area of prototyping and testing.

#### Round 1

The Round 1 survey instrument was made available to participants online from June 19 to June 28, 2006. Each participant was contacted via email and directed to access the study website in order to record their responses to the four research questions:

1. What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?



2. What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?
3. What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?
4. What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

The survey instrument was completed by 15 of the 22 persons who had agreed to participate.

#### Establishing Validity

A total of 234 responses (see Appendix D) were received from the 15 participants during Round 1. In order to establish content validity, this data was sent to Dr. Paul Schrueders and Dr. Tim Taylor, engineering professors at Utah State University, so that they could review the entire list of responses and condense the data into a list of unique items. The professional literature regarding the Delphi research process recommends a panel of at least two persons to monitor this process (Turoff, 1970) of identifying the items that will form the Round 2 survey instrument. Table 11 contains the reviewed list of all unique responses as created by Drs. Schrueders and Taylor.

#### Table 11

##### Results of Round One Data Review

##### Question 1

What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems

1. Understand
  - 1.1. Problem identification/formulation/development of requirements lists
  - 1.2. Functional structures
  - 1.3. Customer needs
2. Manage
  - 2.1. Project planning and scheduling
  - 2.2. Teamwork

- 2.3. Decision making methodologies
- 2.4. Communication
  - 2.4.1. Written
  - 2.4.2. Oral
  - 2.4.3. Graphical/pictorial
- 2.5. Negotiation
- 2.6. Meeting skills
- 2.7. Personal ethics
- 2.8. Multicultural/diversity awareness
- 3. Solve
  - 3.1. Ability to break down complex problems in manageable pieces
  - 3.2. Ability to handle open-ended/ill-defined problems
  - 3.3. Ability to integrate multiple domains of knowledge
  - 3.4. Acceptance of multiple solutions to a single problem
  - 3.5. Brainstorming and innovative concept generation
  - 3.6. Conceptual design
  - 3.7. Design for robustness/failure mode analysis
  - 3.8. Engineering heuristics for/analysis-based design
  - 3.9. Experimental design, data collection, and interpretation of results
  - 3.10. Functional product modeling
  - 3.11. Human factors and safety in design
  - 3.12. Identification of good/bad design
  - 3.13. Identification of underlying scientific principles
  - 3.14. Problem identification/formulation/development of requirements lists
  - 3.15. Product optimization
  - 3.16. Product testing/functional analysis
  - 3.17. Prototyping/fabrication skills
  - 3.18. Recognition that the solution method depends on the type of problem at hand
  - 3.19. Research/library skills
  - 3.20. Simplicity and clarity of use and function
  - 3.21. Synthesis of simple parts into more complex system.
  - 3.22. Understanding product life cycles/life cycle analysis
- 4. General Skills
  - 4.1. Critical thinking
  - 4.2. Experience
  - 4.3. Logic and logical thinking
  - 4.4. Systems thinking

## Question 2

What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?

1. Algebra
  - 1.1. Basic Algebra
  - 1.2. Advanced Algebra
  - 1.3. Linear Algebra
2. Geometry
3. Trigonometry
4. Pre-Calculus
5. Statistics
6. Calculus
  - 6.1. Integration
  - 6.2. Differentiation
  - 6.3. Differential equations
7. Skills and Concepts
  - 7.1. Measurement theory
  - 7.2. Approximation
8. Problem formulation
  - 8.1. Ability to handle open-ended/ill-defined problems
  - 8.2. Multiple solutions to a single problem
  - 8.3. Optimization
9. Computer Skills
  - 9.1. Programming
  - 9.2. Spreadsheets
  - 9.3. Modeling/simulation/numerical analysis software

### Question 3

What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?

1. Chemistry
  - 1.1. Materials properties
  - 1.2. Effects chemical formulation on manufacturing
2. Biology
  - 2.1. Evolution
3. Physics
  - 3.1. Conservation of mass, energy, and momentum
  - 3.2. Dynamic systems
  - 3.3. Introductory mechanics
  - 3.4. Newton's laws: forces, reactions, velocity & acceleration
  - 3.5. Summation of forces/force equilibrium
  - 3.6. Types of energy
4. Engineering
  - 4.1. Circuit analysis and electrical power
  - 4.2. Control theory
  - 4.3. Fluid flow
  - 4.4. Heat and mass balances

- 4.5. Heat transfer
- 4.6. Statics
- 4.7. Strength of materials
- 4.8. Thermodynamics
- 5. Education/Learning Theory
  - 5.1. Decision analysis
  - 5.2. Cognitive science
  - 5.3. Learning theories

#### Question 4

What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

- 1. Project Management
  - 1.1. Communications
    - 1.1.1. Written
    - 1.1.2. Oral
    - 1.1.3. Graphical/pictorial
  - 1.2. Decision making principles and methods
  - 1.3. Meeting skills
  - 1.4. Multicultural/diversity awareness
  - 1.5. Negotiation
  - 1.6. Personal ethics
  - 1.7. Project planning and scheduling
  - 1.8. Teamwork
- 2. Computer Skills
  - 2.1. Computer aided design software
  - 2.2. Computer searching
  - 2.3. E-mail
  - 2.4. Modeling/simulation/numerical analysis software
  - 2.5. Plotting Software
  - 2.6. Presentation software
  - 2.7. Spread Sheets
- 3. General Skills
  - 3.1. Ability to abstract
  - 3.2. Ability to synthesize
  - 3.3. Analogical reasoning
  - 3.4. Common sense
  - 3.5. Critical thinking
  - 3.6. Historical perspective
  - 3.7. Logical thinking
- 4. Problem Solving/Design Skills
  - 4.1. Ability to break down complex problems in manageable pieces.
  - 4.2. Ability to handle open-ended/ill-defined problems
  - 4.3. Ability to integrate multiple domains of knowledge

- 4.4. Acceptance of multiple solutions to a single problem
- 4.5. Analysis-based design
- 4.6. Basic mechanical mechanisms
- 4.7. Brainstorming and innovative concept generation
- 4.8. Conceptual design
- 4.9. Dealing with multiple solutions to a single problem
- 4.10. Design for robustness/failure mode analysis
- 4.11. Engineering heuristics for/analysis-based design
- 4.12. Experimental design, data collection, and interpretation of results
- 4.13. Failure mode and effects analysis
- 4.14. Functional product modeling
- 4.15. Human factors and safety in design
- 4.16. Identification of good/bad design
- 4.17. Identification of underlying scientific principles
- 4.18. Problem identification/formulation/development of requirements lists
- 4.19. Product dissection
- 4.20. Product optimization
- 4.21. Product testing/functional analysis
- 4.22. Prototyping/fabrication skills
- 4.23. Recognition that the solution method depends on the type of problem at hand.
- 4.24. Research/library skills
- 4.25. Synthesis of simple parts into more complex system.
- 4.26. Understanding product life cycles/life cycle analysis

## Round 2

The list of unique responses identified by Drs. Schrueders and Taylor during the review process (see Table 11) became the items in the Round 2 survey instrument (see Appendix E). The online survey was made available from July 10 to July 19, 2006. Participants were contacted via email and directed to access the online survey in order to indicate their level of agreement with each item on a 6-point Likert scale. Table 12 displays the format for each item on the survey.

Table 12

Example: Item 1

1. Understand problem identification / formulation / development of requirements lists

Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6

Thirteen of the original 15 participants from Round 1 completed the survey by the July 19 deadline. Table 13 displays the results.

Table 13

Round Two Results

Research Question One: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?				
ITEM	Mean	Median	SD	IQR
1. Understand problem identification/ formulation /development of requirements lists	5.85	6	0.3755	6
2. Understand functional structures	4.77	5	1.3634	4-6
3. Understanding of customer needs	5.31	5	0.8549	5-6
4. Project planning and scheduling	4.92	5	0.7596	4-5
5. Teamwork	5.23	5	0.5991	5-6
6. Decision making methodologies	4.62	5	1.0439	4-5
7. Written communication	5.23	5	0.8321	5-6
8. Oral communication	5.54	6	0.5189	5-6
9. Graphical/pictorial communication	5.23	5	0.7250	5-6
10. Negotiation	4.15	4	0.8006	4
11. Meeting skills	4.54	4	0.6602	4-5
12. Personal ethics	5.00	5	0.7071	5
13. Multicultural/diversity awareness	4.38	5	1.2609	4-5
14. Ability to break down complex problems in manageable pieces	5.00	5	0.8165	4-6

15. Ability to handle open-ended/ill defined problems	5.46	6	0.6602	5-6
16. Ability to integrate multiple domains of knowledge	5.31	6	0.9473	5-6
17. Acceptance of multiple solutions to a single problem	5.62	6	0.5064	5-6
18. Brainstorming and innovative concept generation	5.00	5	0.5774	5
19. Conceptual design	5.42	5	0.5149	5-6
20. Design for robustness/failure mode analysis	3.85	4	1.0682	4
21. Engineering heuristics for analysis-based design	3.92	4	1.3790	3.75-5
22. Experimental design, data collection, and interpretation of results	4.46	4	0.7763	4-5
23. Functional product modeling	4.31	4	0.8549	4-5
24. Human factors and safety in design	4.54	5	0.5189	4-5
25. Identification of good/bad design	4.77	5	0.7250	4-5
26. Identification of underlying scientific principles	4.77	5	0.8321	4-5
27. Product optimization	3.54	4	0.8771	3-4
28. Product testing/functional analysis	4.46	5	0.8771	4-5
29. Prototyping/fabrication skills	4.85	5	0.8006	4-5
30. Recognition that the solution method depends on the type of problem at hand	4.31	4	0.8549	4-5
31. Research/library skills	4.62	5	1.0439	4-5
32. Simplicity and clarity of use and function	4.54	4	0.6602	4-5
33. Synthesis of simple parts into more complex system	4.54	5	0.7763	4-5
34. Understanding product life cycles/life cycle analysis	4.38	4	0.7679	4-5
35. Critical thinking	5.23	5	0.8321	5-6
36. Experience	4.00	4	1.2910	3-5
37. Logic and logical thinking	4.92	5	0.6405	5
38. Systems thinking	5.31	6	0.8549	5-6

Research Question Two: What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?

ITEM	Mean	Median	SD	IQR
40. Basic Algebra	5.38	6	0.7679	5-6
41. Advanced Algebra	4.85	5	1.1435	4-6
42. Linear Algebra	4.00	4	1.0000	3-5
43. Geometry	5.15	5	0.6887	5-6
44. Trigonometry	5.17	5	0.7177	5-6
45. Pre-Calculus	4.75	5	0.6216	4-5
46. Statistics	4.85	5	0.8987	4-6
47. Calculus- Integration	4.62	5	0.9608	4-5
48. Calculus- Differentiation	4.62	5	0.9608	4-5
49. Calculus- Differential Equations	3.92	4	0.7596	4
50. Measurement theory	4.23	4	0.7250	4
51. Approximation	5.08	5	1.0377	4-6
52. Ability to handle open-ended/ill defined problems	5.62	6	0.6504	5-6
53. Multiple solutions to a single problem	5.46	6	0.6602	5-6
54. Optimization	3.31	4	1.1094	3-4
55. Computer Programming	4.23	4	1.0919	4-5
56. Spreadsheets	5.15	5	0.8006	5-6
57. Modeling/simulation/numerical analysis software	4.46	4	0.9674	4-5

Research Question Three: What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?

ITEM	Mean	Median	SD	IQR
59. Chemical properties of materials	4.17	4	0.5774	4-4.25
60. Effects of chemical formulation on manufacturing	3.38	3	1.0439	3-4
61. Biological Evolution	3.31	3	1.3775	2-4
62. Conservation of mass, energy, and momentum	-		-	-
63. Dynamic systems	4.23	4	0.5991	4-5
64. Introductory mechanics	4.77	5	0.7250	4-5
65. Newton's laws: forces, reactions, velocity & acceleration	5.31	5	0.6304	5-6



66. Summation of forces/force equilibrium	5.08	5	0.6405	5
67. Types of energy	5.23	5	0.5991	5-6
68. Circuit analysis and electrical power	4.08	4	0.4935	4
69. Control theory	3.00	3	1.0000	2-4
70. Fluid flow	3.77	4	0.5991	3-4
71. Heat and mass balances	3.92	4	0.7596	3-4
72. Heat transfer	4.08	4	0.7930	4
73. Statics	5.00	5	0.7385	4-75-5.25
74. Strength of materials	4.69	5	0.9473	4-5
75. Thermodynamics	3.85	4	1.0682	3-4
76. Decision analysis	3.77	3	1.4233	3-4
77. Cognitive science	3.62	4	1.3868	2-5
78. Learning theories	3.62	3	1.5021	3-4
Research Question Four: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?				
ITEM	Mean	Median	SD	IQR
80. Computer aided design software	4.46	5	0.8771	4-5
81. Computer searching	4.38	5	1.3253	4-5
82. E-mail	4.83	5	0.8348	4.75-5
83. Plotting Software	4.62	5	0.7679	4-5
84. Presentation software	4.85	5	0.8987	4-5
85. Ability to abstract	5.23	5	0.8321	5-6
86. Ability to synthesize	5.69	6	0.4804	5-6
87. Analogical reasoning	5.08	5	0.6686	5-5.25
88. Historical perspective	4.46	4	0.8771	4-5
89. Analysis-based design	4.23	4	0.9268	4
90. Basic mechanical mechanisms	4.23	4	0.7250	4-5
91. Failure mode and effects analysis	3.85	4	0.9871	3-4
92. Product Dissection	5.23	5	0.5991	5-6

The Round 2 survey also included space for participants to add additional items they felt should be included in order to more fully answer the four research questions. Table 14 displays the comments and new survey items submitted by participants during Round 2.

## Table 14

### Round 2 Additions and Comments

#### Research Question 1

- The above is quite a comprehensive list.
- Some basics of costing, profit, and economic analysis
- Understanding the context within which the technological problem exists and the possible effects of external influences on the situation.
- You listed most topics in my book “The Mechanical Design Process” so I naturally think they are all very important or close to it. You got most of them.
- Product architecture and modularity/interfaces; design principles to assist in generating innovative concepts; design-by-analogy and analogical reasoning to generate innovative concepts
- Nearly all the above are important--the issue is deciding which ones are most important.

#### Research Question 2

- Algebraic equations for gear ratios, conservation of energy, conservation of momentum, projectile motion, structural equilibrium, basic stresses
- I think this is all backwards the attraction of designing and making their own stuff can motivate the students to learn math. I wouldn't focus on what they need to know, but focus on what they can learn by being motivated to create things.

#### Research Question 3

- This depends a great deal on the types of engineering design problems presented
- Project management
- Thermal expansion and contraction

#### Research Question 4

- Reverse engineering
- Finishing a job to the last detail
- Recognize team roles and personality types

### Round 3

The Round 3 survey instrument (see Appendix G) was made available online from July 24, 2006 to August 2, 2006. Each participant was emailed Round 2 survey responses to remind each of the previous choices. The 13 participants who completed Round 2 also completed this survey by the deadline. The survey contained all survey items from Round 2 along with statistical data. The mean, maximum, minimum, standard deviation and interquartile range were calculated for each item and displayed for the participants. Table 15 displays item one from the

survey as an example of how each item appeared to participants. At this point a numeric score was also displayed alongside each choice so that the statistical data would be readily understood by participants.

Table 15

Item 1 – Round 3 (Round 2 statistical data included).

1. Understand problem identification / formulation / development of requirements lists (Round Two Data: Mean= 5.85, Max=6, Min=5, St. Dev.= 0.3755, IQR= 6)

Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6

In addition to the original items and corresponding statistical data, fifteen new items suggested by participants in Round 2 were added to the Round 3 survey instrument. Since these were new items, they were identified as such and had no statistical data brought forward from the previous round. Table 16 displays the results of Round 3.

Table 16

## Round 3 Data

Research Question 1: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?				
<u>ITEM</u>	<u>Mean</u>	<u>Median</u>	<u>SD</u>	<u>IQR</u>
1. Understand problem identification/ formulation /development of requirements lists	5.38	6	1.3868	5-6
2. Understand functional structures	4.00	4	1.5811	4-5
3. Understanding of customer needs	5.00	5	1.4142	5-6
4. Project planning and scheduling	4.54	4	0.8771	4-5
5. Teamwork	5.31	5	0.6304	5-6
6. Decision making methodologies	4.58	4.5	1.0836	4-5.25
7. Written communication	5.46	6	0.6602	5-6
8. Oral communication	5.54	6	0.5189	5-6
9. Graphical/pictorial communication	5.54	6	0.5189	5-6
10. Negotiation	4.46	4	0.9674	4-5
11. Meeting skills	4.62	5	0.6504	4-5
12. Personal ethics	5.15	5	0.6887	5-6
13. Multicultural/diversity awareness	4.08	4	1.1152	4
14. Ability to break down complex problems in manageable pieces	5.17	5	0.7177	5-6
15. Ability to handle open-ended/ill defined problems	5.77	6	0.4385	6
16. Ability to integrate multiple domains of knowledge	5.08	5	1.1152	5-6

17. Acceptance of multiple solutions to a single problem	5.77	6	0.4385	6
18. Brainstorming and innovative concept generation	5.15	5	0.8006	5-6
19. Conceptual design	5.23	5	0.7250	5-6
20. Design for robustness/failure mode analysis	3.54	4	1.2659	3-4
21. Engineering heuristics for analysis-based design	3.75	4	1.3568	3-4.25
22. Experimental design, data collection, and interpretation of results	4.54	5	0.5189	4-5
23. Functional product modeling	4.46	5	0.8771	4-5
24. Human factors and safety in design	4.62	5	0.5064	4-5
25. Identification of good/bad design	4.62	5	0.7679	4-5
26. Identification of underlying scientific principles	4.92	5	0.8623	4-6
27. Product optimization	3.00	3	0.8165	3
28. Product testing/functional analysis	4.38	4	0.7679	4-5
29. Prototyping/fabrication skills	4.77	5	0.5991	4-5
30. Recognition that the solution method depends on the type of problem at hand	4.62	4	0.7679	4-5
31. Research/library skills	4.85	5	0.8006	4-5
32. Simplicity and clarity of use and function	4.77	5	0.8321	4-5
33. Synthesis of simple parts into more complex system	4.69	5	0.6304	4-5
34. Understanding product life cycles/life cycle analysis	4.38	4	0.8697	4-5
35. Critical thinking	5.23	5	0.8321	5-6
36. Experience	3.62	3	1.1929	3-4
37. Logic and logical thinking	4.85	5	0.6887	4-5
38. Systems thinking	5.69	6	0.4804	5-6
39a. Costing, profit, and basic economic analysis	3.92	4	0.8623	4

39b. Understanding the context of the technological problem and possible external influences	4.77	5	1.1658	5
39c. Product architecture and modularity/interfaces	3.92	4	1.1875	3-4
39d. Design principles to assist in generating innovative concepts	4.38	4	0.9608	4-5
39e. Design by analogy	4.00	4	0.8165	4
Research Question 2: What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?				
<u>ITEM</u>	<u>Mean</u>	<u>Median</u>	<u>SD</u>	<u>IQR</u>
40. Basic Algebra	5.54	6	0.6602	5-6
41. Advanced Algebra	4.62	5	1.1929	4-5
42. Linear Algebra	3.62	4	1.1209	3-4
43. Geometry	5.46	6	0.7763	5-6
44. Trigonometry	5.00	5	0.9129	5-6
45. Pre-Calculus	4.62	4	1.1209	4-5
46. Statistics	4.23	5	1.5892	3-5
47. Calculus- Integration	3.77	4	1.7394	2-5
48. Calculus- Differentiation	3.77	4	1.7394	2-5
49. Calculus- Differential Equations	3.08	4	1.3205	2-4
50. Measurement theory	3.46	4	1.4500	2-4
51. Approximation	4.54	5	1.0500	4-5
52. Ability to handle open-ended/ill defined problems	5.54	6	0.6602	5-6
53. Multiple solutions to a single problem	5.69	6	0.4804	5-6
54. Optimization	2.85	3	1.1435	2-3
55. Computer Programming	3.92	4	1.3821	4
56. Spreadsheets	5.23	5	0.9268	5-6
57. Modeling/simulation/numerical analysis software	3.92	4	1.5525	3-5
58a. Algebraic equations for determining gear ratios	2.75	3	1.4222	1.75-3
58b. Conservation of momentum	4.25	4	1.2154	4-5
58c. Projectile motion	3.45	4	1.4397	3-4
58d. Structural equilibrium	4.33	4	0.9847	4-5
58e. Basic stresses	4.25	4	1.2154	3.75-5

Research Question 3: What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?

<u>ITEM</u>	<u>Mean</u>	<u>Median</u>	<u>SD</u>	<u>IQR</u>
59. Chemical properties of materials	3.83	4	1.0299	4
60. Effects of chemical formulation on manufacturing	2.75	3	0.7538	2.75-3
61. Biological Evolution	3.17	3	1.5859	2.5-4
62. Conservation of mass, energy, and momentum	4.92	5	1.2401	4-6
63. Dynamic systems	4.08	4	1.0836	4-5
64. Introductory mechanics	4.45	4	0.9342	4-5
65. Newton's laws: forces, reactions, velocity & acceleration	5.42	5.5	0.6686	5-6
66. Summation of forces/ force equilibrium	5.00	5	0.6030	5
67. Types of energy	5.25	5	0.6216	5-6
68. Circuit analysis and electrical power	3.75	4	0.6216	4
69. Control theory	2.83	3	1.3371	2.5-3
70. Fluid flow	3.42	4	0.7930	3-4
71. Heat and mass balances	3.58	4	0.7930	3-4
72. Heat transfer	3.58	4	0.7930	3-4
73. Statics	4.50	5	1.0000	4-5
74. Strength of materials	4.25	4.5	1.1382	3.75-5
75. Thermodynamics	3.25	3	0.8660	3-4
76. Decision analysis	3.33	3	1.1547	3-4
77. Cognitive science	3.08	3	1.1645	2-4
78. Learning theories	3.58	3	1.6214	3-4.5
79a. Project management	4.17	4	1.2673	3-5
79b. Thermal expansion/ contraction	3.92	4	0.7930	4

Research Question 4: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

<u>ITEM</u>	<u>Mean</u>	<u>Median</u>	<u>SD</u>	<u>IQR</u>
80. Computer aided design software	4.33	4.5	1.2309	3.75-5
81. Computer searching	4.92	5	0.7930	4-5.25
82. E-mail	5.18	5	0.6030	5-5.5
83. Plotting Software	4.50	4.5	0.7977	4-5
84. Presentation software	5.00	5	0.7385	4.75-5.25
85. Ability to abstract	5.17	5	0.7177	5-6
86. Ability to synthesize	5.75	6	0.4523	5.75-6
87. Analogical reasoning	5.17	5	0.7177	5-6
88. Historical perspective	4.42	4.5	1.1645	4-5
89. Analysis-based design	4.25	4	1.4222	4-5.25
90. Basic mechanical mechanisms	4.17	4	0.8348	4-4.25
91. Failure mode and effects analysis	3.00	3	1.2060	2.75-4
92. Product Dissection	4.58	5	0.9962	4-5
93a. Reverse engineering	4.17	4	1.4668	4-5
93b. Finishing job to the last detail	3.92	4	1.4434	3-5
93c. Recognizing team roles and personality types	4.58	4	0.7930	4-5

As in Round 2, participants had the opportunity to add any additional items they felt would help to answer the four research questions. Eight additional items were suggested by participants and these items were added to the Round 4 survey instrument. In addition to having the opportunity to add new survey items, participants were encouraged to provide an explanation of their answer on any particular item. Table 17 contains both the new items suggested and the comments given by participants whose choices were outside the interquartile range.



## Table 17

### Round 3 Additions and Comments

#### Question 1

- More advanced high school students may be interested in understanding basic business motivations for engineering design, such as marketing or consumer research
- These questions have done a good job covering the topics. Perhaps basic manufacturing processes could be another topic.
- House of Quality methodology

#### Question 2

- The following are getting too fine!!
- Scaling. Using geometry & trig to understand how to scale the size of a component up or down.
- Any formula expressing the performance of a system (there is no one single formula since each system is unique).
- No - I think that students should be getting turned on to making and designing new things - and understanding what engineers do. The design should motivate the math learning, not the other way around.

#### Question 3

- leadership principles, environmentally conscious principles
- Question Asking (Inquiry)
- Again, I think that engineering for high school students should not turn into mini science courses. They should focus on what is different about engineering: creating new stuff. Whatever math/science is needed for the particular problem should be taught/learned. The program shouldn't be driven by delivering particular math/science content.

#### Question 4

- Engineering intuition. It is important in all this that students don't get caught up in entirely in the calculations. Several researchers have discussed the need to develop a student's sense of a problem first (Margot Brereton calls it "Synalysis").

#### Outside IQR Explanation

- For Q61, I put "1" since biological evolution has some scientific evidence to support it at the micro-evolution level but no evidence to support it at the macro-level. The concept of micro-evolution would be somewhat valuable to learn, but I don't feel like the general concept of evolution would be valuable.
- 7. We now that informal communication plays an under-recognized role in design team interactions. Although it is highly relevant, formal communication is overemphasized in design/engineering education--maybe because it is easier to teach formal communication practices than informal communication practices. 10. There is a large body of evidence that suggests design, among many other things, IS negotiation. Negotiation requires mental flexibility, which is critical for being able to understand and reframe context. 13. If one is to understand and relate to users from diverse backgrounds, and drive his/her design process with

that understanding, one must have the highest awareness of multicultural issues. 69. Control theory is applicable to all engineering domains and is critical for understanding the behavior of all engineering systems. 76. Decision analysis is applicable to design practice in all engineering domains, and facilitates the application of well-considered design processes. 78. Design is a learning-intensive activity. One cannot master designing without understanding his/her learning processes.

#### Round 4

The Round 4 survey was available online from August 7 to 16, 2006. Since the literature supports a three-round Delphi (Linstone & Murray, 1975) and also indicates that most changes will occur in early rounds of the Delphi study (Dalkey & Helmer, 1963; Dalkey, 1968), it was decided to only include items in the Round 4 survey instrument (see Appendix I) that met one or more of the following criteria:

1. Items that had a mean shift of  $>15\%$  between Round 2 and Round 3 was considered to be unstable and were included in Round 4.
2. Items with an Interquartile Range of  $>1$  had not reached the level of consensus desired and was included in Round 4.
3. Items which had been commented on during Round 3 were included in Round 4 along with the comments so that all participants could see their colleagues' feedback.
4. Items that were added in Round 3 were included in Round 4.

Fifty items fell into one or more of these categories and were included in the Round 4 survey instrument (see Appendix I). Each participant was emailed Round 3 survey responses to remind each of the previous choices. Twelve of the thirteen participants who completed the Round 3 survey accessed and completed the Round 4 survey by the deadline. Each item on the survey that was brought forward from previous rounds had the associated statistical data (mean, maximum, minimum, standard deviation, and interquartile range) listed beside the question. In addition, any comments made by participants whose previous answers were outside the interquartile range (IQR) were also listed along with the survey item. Table 18 displays the results of the Round 4 survey.

Table 18

## Round 4 Results

Research Question 1: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?				
ITEM	Mean	Median	SD	IQR
2. Understand functional structures	4.25	4	1.5448	4-5.25
6. Decision making methodologies	4.58	5	1.1645	4-5
7. Written communication	5.08	5	0.9003	5-6
10. Negotiation	4.42	4	0.7930	5-6
13. Multicultural/diversity awareness	4.08	4	1.0836	4
21. Engineering heuristics for analysis-based design	3.45	4	1.4397	2.5-4
26. Identification of underlying scientific principles	5.08	5	0.7930	4.75-6
27. Product optimization	3.08	3	0.9962	3-3.25
39a. Costing, profit, and basic economic analysis	3.50	3.5	1.000	3-4
39b. Understanding the context of the technological problem and possible external influences	4.75	5	0.9653	4-5.25
39c. Product architecture and modularity/interfaces	3.67	4	1.1547	3-4
39d. Design principles to assist in generating innovative concepts	4.67	5	0.8876	4-5
39e. Design by analogy	4.17	4	0.5774	4
39f. Understanding basic business motivations for engineering design, such as marketing or consumer research	4.00	4	1.1282	3.75-5
39g. Understanding basic manufacturing processes	4.25	4	0.8660	4-5
39h. House of Quality method	3.25	3	1.3568	2.75
Research Question 2: What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?				
ITEM	Mean	Median	SD	IQR
46. Statistics	4.25	4	1.3568	4-5
47. Calculus- Integration	3.25	3.5	1.2881	2-4
48. Calculus- Differentiation	3.17	3.5	1.4035	2-4

49. Calculus- Differential Equations	2.73	3	1.2721	2-3.5
50. Measurement theory	3.17	3.5	1.2673	2.75-4
57. Modeling/simulation/numerical analysis software	3.64	3	1.6895	3-5
58a. Algebraic equations for determining gear ratios	2.83	2.5	1.5275	3-5
58b. Conservation of momentum	4.08	4	1.2401	4-5
58c. Projectile motion	3.25	3	1.3568	3-4
58d. Structural equilibrium	4.50	4	0.6742	4-5
58e. Basic stresses	4.42	4	0.7930	4-5
58f. Using geometry and trigonometry to change the scale of a component	3.92	4	0.7930	3-4.25
58g. Formulas capable of expressing the performance of a system	4.25	4	1.2154	3.75-5
<p>Research Question 3: What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?</p>				
ITEM	Mean	Median	SD	IQR
60. Effects of chemical formulation on manufacturing	2.50	2.5	0.7977	2-3
61. Biological Evolution	3.00	3	1.4142	2-4
62. Conservation of mass, energy, and momentum	4.67	4.5	0.9847	4-5.25
69. Control theory	2.83	3	1.3371	1.75-4
74. Strength of materials	4.42	5	1.0836	4-5
75. Thermodynamics	3.33	3	0.8876	3-4
76. Decision analysis	3.67	3.5	1.4355	3-5
78. Learning theories	3.50	3	1.5076	3-4.25
79a. Project management	4.25	4	1.0553	3.75-5
79b. Thermal expansion/contraction	4.00	4	0.8528	3.75-4
79c. Question asking -inquiry	4.58	5	0.7930	4-5
79d. Leadership principles	3.58	4	1.0836	3.75-4
79e. Principles related to environmental consciousness	4.42	4.5	0.6686	4-5

Research Question 4: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

ITEM	Mean	Median	SD	IQR
80. Computer aided design software	4.00	4	1.1282	3.75-5
81. Computer searching	4.67	5	0.8876	4-5
89. Analysis-based design	4.17	4	1.2673	4-5
91. Failure mode and effects analysis	3.08	3	1.2401	2.75-4
93a. Reverse engineering	4.17	4	1.1934	4-5
93b. Finishing job to the last detail	3.67	3.5	1.4975	3-4.25
93c. Recognizing team roles and personality types	4.58	4.5	0.6686	4-5
93d. Engineering intuition	3.45	4	1.3685	2.5-4.5

### Final Results

The final results for each item appear below in Table 19. In addition to the mean, median, standard deviation, and interquartile range scores, the mean shift during the previous two rounds is reported for each item. This score indicates the degree of stability for each individual item, while the IQR indicates the level of consensus afforded the item by the participants. As described in the methods section of this study, an IQR score of  $\leq 1$  is considered to be an indication that the item has reached an acceptable degree of consensus. A mean shift (or  $\Delta$  Mean) of  $< 15\%$  is an indication that the item can be considered stable.

The literature was vague as to the method used in attributing different levels of significance to the statistical scores that result from Delphi studies. Based upon personal correspondence with Wicklein (September 25, 2006) and Rojewski (September 30, 2006), a decision was made to maintain the highest standards for the purpose of this study. It was determined that applying the most stringent criteria to the data resulting from the Delphi process would ensure that only items that were undeniably very important would be placed in the highest category and considered in the conclusions and recommendations. All other items would fall

into a secondary category of lesser importance. Items considered to be very important for the purposes of this research met each of the following criteria:

1. An inter-round mean  $\Delta$  of <15% (indicating stability)
2. A median score of 5 or 6 (indicating a strong level of agreement among participants)
3. An IQR range of  $\leq 1$  (indicating consensus)

Forty-eight (48) items met these strict requirements and are identified in Table 19 with double asterisk (\*\*) symbols. Only these items that met the strictest requirements would be considered valid for identifying the essential aspects and related academic concepts of an engineering design process in secondary technology education curriculum.

Table 19

Final Results by Item

Research Question 1: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?					
ITEM	Mean	$\Delta$ Mean (%)	Median	SD	IQR
**1. Understand problem identification/ formulation /development of requirements lists	5.38	-7.97	6	1.3868	5-6
2. Understand functional structures	4.25	-4.35	4	1.5448	4-5.25
**3. Understanding of customer needs	5.00	-5.80	5	1.4142	5-6
4. Project planning and scheduling	4.54	-7.78	4	0.8774	4-5
**5. Teamwork	5.31	1.51	5	0.6304	5-6
**6. Decision making methodologies	4.58	-2.82	5	1.1645	4-5
**7. Written communication	5.08	4.38	5	0.9003	5-6
**8. Oral communication	5.54	0.03	6	0.5189	5-6
**9. Graphical/pictorial communication	5.54	5.91	6	0.5189	5-6
10. Negotiation	4.42	-0.90	4	0.7930	5-6
**11. Meeting skills	4.62	1.80	5	0.6504	4-5
**12. Personal ethics	5.15	3.00	5	0.6887	5-6
13. Multicultural/diversity awareness	4.08	0.00	4	1.0836	4

**14. Ability to break down complex problems in manageable pieces	5.17	3.40	5	0.7177	5-6
**15. Ability to handle open-ended/ill defined problems	5.77	5.65	6	0.4385	6
**16. Ability to integrate multiple domains of knowledge	5.08	-4.29	5	1.1152	5-6
**17. Acceptance of multiple solutions to a single problem	5.77	2.75	6	0.4385	6
**18. Brainstorming and innovative concept generation	5.15	3.00	5	0.8006	5-6
**19. Conceptual design	5.23	-3.45	5	0.7250	5-6
20. Design for robustness/failure mode analysis	3.54	-7.96	4	1.2659	3-4
21. Engineering heuristics for analysis-based design	3.45	-8.70	4	1.4397	2.5-4
**22. Experimental design, data collection, and interpretation of results	4.54	1.76	5	0.5189	4-5
**23. Functional product modeling	4.46	3.54	5	0.8771	4-5
**24. Human factors and safety in design	4.62	1.80	5	0.5064	4-5
**25. Identification of good/bad design	4.62	-3.13	5	0.7679	4-5
26. Identification of underlying scientific principles	5.08	3.16	5	0.7930	4.75-6
27. Product optimization	3.08	2.60	3	0.9962	3-3.25
28. Product testing/functional analysis	4.38	-1.83	4	0.7679	4-5
**29. Prototyping/fabrication skills	4.77	-1.57	5	0.5991	4-5
30. Recognition that the solution method depends on the type of problem at hand	4.62	7.25	4	0.7679	4-5
**31. Research/library skills	4.85	5.08	5	0.8006	4-5
**32. Simplicity and clarity of use and function	4.77	5.10	5	0.8321	4-5
**33. Synthesis of simple parts into more complex system	4.69	3.34	5	0.6304	4-5
34. Understanding product life cycles/life cycle analysis	4.38	-0.11	4	0.8697	4-5
**35. Critical thinking	5.23	-0.01	5	0.8321	5-6
36. Experience	3.62	-9.50	3	1.1929	3-4
**37. Logic and logical thinking	4.85	-1.48	5	0.6887	4-5
**38. Systems thinking	5.69	7.20	6	0.4804	5-6
39a. Costing, profit, and basic economic analysis	3.50	-12.00	3.5	1.000	3-4

39b. Understanding the context of the technological problem and possible external influences	4.75	-0.42	5	0.9653	4-5.25
39c. Product architecture and modularity/interfaces	3.67	-6.81	4	1.1547	3-4
**39d. Design principles to assist in generating innovative concepts	4.67	6.21	5	0.8876	4-5
39e. Design by analogy	4.17	4.08	4	0.5774	4
39f. Understanding basic business motivations for engineering design, such as marketing or consumer research	4.00	N/A	4	1.1282	3.75-5
39g Understanding basic manufacturing processes	4.25	N/A	4	0.8660	4-5
39h House of Quality method	3.25	N/A	3	1.3568	2.75-4
Research Question 2: What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?					
ITEM	Mean	$\Delta$ Mean (%)	Median	SD	IQR
**40. Basic Algebra	5.54	2.89	6	0.6602	5-6
**41. Advanced Algebra	4.62	-4.67	5	1.1929	4-5
42. Linear Algebra	3.62	-9.50	4	1.1209	3-4
**43. Geometry	5.46	5.94	6	0.7763	5-6
**44. Trigonometry	5.00	-3.23	5	0.9129	5-6
**45. Pre-Calculus	4.62	-2.74	5	1.1209	4-5
46. Statistics	4.25	0.47	4	1.3568	4-5
47. Calculus- Integration	3.25	-16.00	3.5	1.2881	2-4
48. Calculus- Differentiation	3.17	-18.93	3.5	1.4035	2-4
49. Calculus- Differential Equations	2.73	-12.82	3	1.2721	2-3.5
50. Measurement theory	3.17	6.74	3	1.2673	2.75-4
**51. Approximation	4.54	-10.58	5	1.0500	4-5
**52. Ability to handle open-ended/ill defined problems	5.54	-1.34	6	0.6602	5-6
**53. Multiple solutions to a single problem	5.69	4.18	6	0.4804	5-6
54. Optimization	2.85	-13.84	3	1.1435	2-3
55. Computer Programming	3.92	-7.35	4	1.3821	4
**56. Spreadsheets	5.23	1.48	5	0.9268	5-6
57. Modeling/simulation/numerical analysis software	3.64	-7.69	3	1.6895	3-5



58a. Algebraic equations for determining gear ratios	2.83	2.83	2.5	1.5275	3-5
58b. Conservation of momentum	4.08	-4.17	4	1.2401	4-5
58c. Projectile motion	3.25	-6.15	3	1.3568	3-4
58d. Structural equilibrium	4.50	3.78	4	0.6742	4-5
58e. Basic stresses	4.42	3.85	4	0.7930	4-5
58f. Using geometry and trigonometry to change the scale of a component	3.92	N/A	4	0.7930	3-4.25
58g. Formulas capable of expressing the performance of a system	4.25	N/A	4	1.2154	3.75-5
Research Question 3: What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?					
ITEM	Mean	$\Delta$ Mean (%)	Median	SD	IQR
59. Chemical properties of materials	3.83	-8.08	4	1.0299	4
60. Effects of chemical formulation on manufacturing	2.50	-10.00	2.5	0.7977	2-3
61. Biological Evolution	3.00	-5.67	3	1.4142	2-4
62. Conservation of mass, energy, and momentum	4.67	-5.35	4.5	0.9847	4-5.25
63. Dynamic systems	4.08	-3.56	4	1.0836	4-5
64. Introductory mechanics	4.45	-6.69	4	0.9342	4-5
**65. Newton's laws: forces, reactions, velocity & acceleration	5.42	2.12	5.5	0.6686	5-6
**66. Summation of forces/force equilibrium	5.00	-1.52	5	0.6030	5
**67. Types of energy	5.25	0.37	5	0.6216	5-6
68. Circuit analysis and electrical power	3.75	-8.02	4	0.6216	4
69. Control theory	2.83	0.00	3	1.3371	1.75-4
70. Fluid flow	3.42	-9.27	4	0.7930	3-4
71. Heat and mass balances	3.58	-8.75	4	0.7930	3-4
72. Heat transfer	3.58	-12.33	4	0.7930	3-4
**73. Statics	4.50	-10.00	5	1.000	4-5
**74. Strength of materials	4.42	3.85	5	1.0836	4-5
75. Thermodynamics	3.33	2.40	3	0.8876	3-4
76. Decision analysis	3.67	9.26	3.5	1.4355	3-5
77. Cognitive science	3.08	-14.81	3	1.1645	2-4
78. Learning theories	3.50	-2.29	3	1.5076	3-4.25
79a. Project management	4.25	1.88	4	1.0553	3.75-5

79b. Thermal expansion/contraction	4.00	2.00	4	0.8528	3.75-4
79c. Question asking -inquiry	4.58	N/A	5	0.7930	4-5
79d. Leadership principles	3.58	N/A	4	1.0836	3.75-4
79e. Principles related to environmental consciousness	4.42	N/A	4.5	0.6686	4-5
Research Question 4: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?					
ITEM	Mean	$\Delta$ Mean (%)	Median	SD	IQR
80. Computer aided design software	4.00	-8.25	4	1.1282	3.75-5
**81. Computer searching	4.67	-5.35	5	0.8876	4-5
**82. E-mail	5.18	7.17	5	0.6030	5-5.5
83. Plotting Software	4.50	-2.50	4.5	0.7977	4-5
**84. Presentation software	5.00	3.17	5	0.7385	4-5
**85. Ability to abstract	5.17	-1.16	5	0.7177	5-6
**86. Ability to synthesize	5.75	1.01	6	0.4523	5.75-6
**87. Analogical reasoning	5.17	1.70	5	0.7177	5-6
88. Historical perspective	4.42	-0.93	4.5	1.1645	4-5
89. Analysis-based design	4.17	-1.92	4	1.2673	4-5
90. Basic mechanical mechanisms	4.17	-1.44	4	0.8348	4-4.25
91. Failure mode and effects analysis	3.08	2.60	3	1.2401	2.75-4
**92. Product Dissection	4.58	-12.44	5	0.9962	4-5
93a. Reverse engineering	4.17	0.00	4	1.1934	4-5
93b. Finishing job to the last detail	3.67	-6.81	3.5	1.4975	3-4.25
93c. Recognizing team roles and personality types	4.58	0.07	4.5	0.6686	4-5
93d. Engineering intuition	3.45	N/A	4	1.3685	2.5-4.5

### Summary

The Delphi technique was used for this research with the goal of adding to the growing body of literature on the subject of engineering design in secondary technology education courses. This study relied on four rounds to elicit the responses of persons considered to be experts in the field of engineering design. Participants accessed the survey instrument for each

round electronically via the Internet. A total of 88 unique items were identified during Round 1 in answer to four open-ended research questions. In subsequent rounds participants suggested an additional 25 items for a total of 113 unique responses. In Rounds 2 through 4 participants indicated their responses on six-point Likert scales. In Rounds 3 and 4, the statistical results from the previous round were reported to participants.

The interquartile range and the inter-round mean score change were two major indices noted for each item in this study. The interquartile range indicated the degree of group consensus and the inter-round mean score change was an indication of item stability. After all four rounds were completed, eighty-four percent of the items (95/113) had achieved an IQR of  $\leq 1$ . A total of 105 of the 113 items had measurable inter-round mean scores. The other eight were items suggested in Round 3 and were thus only included as survey items for one round, which was Round 4. Of these 105 responses, 103 of them (98%) had a mean shift of  $< 15\%$  at the end of all rounds.

It was decided to identify items as very important for the purposes of this study only if they met 3 specific criteria:

1. An inter-round mean  $\Delta$  of  $< 15\%$  (indicating stability)
2. A median score of 5 or 6 (indicating a strong level of agreement among participants)
3. An IQR range of  $\leq 1$  (indicating consensus)

Forty-eight items met these standards and are identified in Table 19 with double asterisk (\*\*) symbols. These 48 items became the basis for the conclusions drawn from this Delphi process and the recommendations made for the field of technology education. Table 20 reports the ranking of each individual item by question. A "T" reported alongside the ranking for any item indicates that there was a tie between items identified for that question. Two items are listed as answers to two different research questions and should be understood in the context of the question they were intended to answer. The items are "Ability to handle open-ended problems" and "Multiple solutions to a single problem."

Table 20

## Mean Score Ranking of Items Identified by Delphi Process

Research Question 1: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?		
ITEM	Mean	Rank (Ques.1)
1. Understand problem identification/ formulation /development of requirements lists	5.38	5
3. Understanding of customer needs	5.00	11
5. Teamwork	5.31	6
6. Decision making methodologies	4.58	17
7. Written communication	5.08	4
8. Oral communication	5.54	3
9. Graphical/pictorial communication	5.54	15
11. Meeting skills	4.62	T16
12. Personal ethics	5.15	T9
14. Ability to break down complex problems in manageable pieces	5.17	8
15. Ability to handle open-ended/ill defined problems	5.77	T1
16. Ability to integrate multiple domains of knowledge	5.08	T10
17. Acceptance of multiple solutions to a single problem	5.77	T1
18. Brainstorming and innovative concept generation	5.15	T9
19. Conceptual design	5.23	T10
22. Experimental design, data collection, and interpretation of results	4.54	18
23. Functional product modeling	4.46	19
24. Human factors and safety in design	4.62	T16
25. Identification of good/bad design	4.62	T16
29. Prototyping/fabrication skills	4.77	T13
31. Research/library skills	4.85	T12
32. Simplicity and clarity of use and function	4.77	T13
33. Synthesis of simple parts into more complex system	4.69	14
35. Critical thinking	5.23	7
37. Logic and logical thinking	4.85	T12
38. Systems thinking	5.69	2
39d. Design principles to assist in generating innovative concepts	4.67	20

Research Question 2: What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?

ITEM	Mean	Rank (Ques.2)
40. Basic Algebra	5.54	T2
41. Advanced Algebra	4.62	T6
43. Geometry	5.46	3
44. Trigonometry	5.00	5
45. Pre-Calculus	4.62	T6
51. Approximation	4.54	7
52. Ability to handle open-ended/ill defined problems	5.54	T2
53. Multiple solutions to a single problem	5.69	1
56. Spreadsheets	5.23	4

Research Question 3: What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?

ITEM	Mean	Rank (Ques. 3)
65. Newton's laws: forces, reactions, velocity & acceleration	5.42	1
66. Summation of forces/force equilibrium	5.00	3
67. Types of energy	5.25	2
73. Statics	4.50	4
74. Strength of materials	4.42	5

Research Question 4: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

ITEM	Mean	Rank (Ques. 4)
81. Computer searching	4.67	5
82. E-mail	5.18	2
84. Presentation software	5.00	4
85. Ability to abstract	5.17	T3
86. Ability to synthesize	5.75	1
87. Analogical reasoning	5.17	T3
92. Product Dissection	4.58	6

## CHAPTER 5

### SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

There has been a growing emphasis in the literature of technology education on the subject of engineering design (ITEA, 2000; ITEA, 2003; ITEA, 2005; Wicklein, 2006) . Some are currently looking to the field of engineering (and engineering design, specifically) as a focus for curriculum organization for the field of technology education (Lewis, 2004; Gorham, 2002; Hailey, et al.2005). It is imperative that professionals in the field of technology education including teachers, administrators, and faculty at teacher preparation institutions have a firm grasp of the nature of engineering design and are properly equipped to merge engineering design content into the existing technology education curriculum. The literature of technology education has indicated a need for research in this area (Hailey, et al., 2005; Pearson & Young; 2002 Wicklein, 2006).

The purpose of this study was to address some of those research needs for the field. Specifically, this study sought to use the Delphi process to elicit the responses of experts in the field of engineering design to four foundational research questions:

1. What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?
2. What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?
3. What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?
4. What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

These research questions were designed to be open-ended and broad in order to help professionals in the field of technology education establish a framework for understanding engineering design in the context of secondary technology education classrooms.

The Delphi process was considered to be an appropriate research methodology for the purposes of this study. The Delphi method is especially suited as a means of facilitating the interaction of a widely dispersed panel of participants. Participants in this study were identified by their peers through a logical, repeatable process. Many phases of this Delphi process including contacting participants and administering survey instruments were carried out via the Internet. A web-based research service was used to facilitate the process. Each survey was available online for 10 days, and participants received email reminders that instructed them to access the website in order to fill out the survey.

This study utilized a four-round Delphi process in order to accomplish the goal of identifying items considered to be important answers to the four research questions. In Round 1 participants were asked to record 5-7 responses to each of the four research questions that were the focus of this study. A total of 234 responses were received. This data was reviewed by Dr. Paul Schrueders and Dr. Tim Taylor at Utah State University. Based on their review, a list of 88 unique responses was established. These items became the basis for Round 2.

The Round 2 survey instrument consisted of the 88 items identified in Round 1. For each individual item, participants were asked to indicate their level of agreement on a 6-point Likert scale. A higher score indicated a higher level of agreement that the item was an appropriate answer to the research question. In addition to indicating their level of agreement with each item, participants were free to add additional items in response to the research questions if they wished.

The Round 3 survey instrument consisted of the original items identified in Round 1 plus 15 items added in Round 2. Participants again accessed the survey electronically and indicated their level of agreement on a six-point Likert scale. In addition, the mean, standard deviation, maximum, minimum and interquartile range were reported alongside each item. Participants

were also emailed their Round 2 scores as a reminder. As in Round 2, participants were free to add any additional items they wished or to make comments. Specifically, participants were asked to provide an explanation if their score on any item was outside the IQR.

As outlined in the Delphi literature, it was possible to drop some items after Round 3 and not include them in Round 4. Items that were included in Round 4 fell into one or more of the following categories:

1. Items that had a mean shift of  $>15\%$  between Round 2 and Round 3 was considered to be unstable and were included in Round 4.
2. Items with an Interquartile Range of  $>1$  had not reached the level of consensus desired and was included in Round 4.
3. Items which had been commented on during Round 3 were included in Round 4 along with the comments so that all participants could see their colleagues' feedback.
4. Items that were added in Round 3 were included in Round 4.

Fifty items fell into one or more of these categories and were included in the Round 4 survey.

The results of the Delphi process were analyzed and reported in Chapter 4 of this research. It was decided to identify items as very important only if they met high standards such as a median score of 5 or 6, IQR of  $\leq 1$  and an inter-round  $\Delta$  mean of  $< 15\%$ . Forty-eight items met these standards and are identified in Table 19.

### General Summary

As professionals in the field of technology education grapple with incorporating engineering design in secondary level classes, several conclusions can be drawn from this research. As the process of curriculum development moves forward, professionals in the field of technology education should make use of research-based content and instructional methodology in the creation of an overall curriculum framework for understanding and implementing engineering design. The development of a curriculum that emphasizes engineering design should be prefaced by the creation of a framework which provides insight from experts in the area of engineering design and extends the current Standards-based context of curriculum development.



Currently there is no overarching framework for the understanding and implementation of engineering design content into secondary technology education classes.

Therefore, the first conclusion to be drawn from this research is that the field is in need of a curriculum framework for the integration of engineering design in technology education classes. The creation and widespread acceptance of such a curriculum framework could help to bring a greater degree of solidarity to a fragmented assortment of approaches to the delivery of technology education courses currently practiced in high schools across the country. This overarching strategy of creating and implementing a solid engineering design focused curriculum framework is necessary to avoid a haphazard and disjointed experience for students and also for teachers attempting to use engineering design as a curriculum organizer.

There are numerous approaches to the delivery of technology education content currently practiced in the United States, and this fragmented approach has led to confusion. It has also eroded the ability of the field to create a unified public image that would give technology education a greater degree of acceptance and influence among high school students, teachers, and parents. Technology teachers have indicated that they feel engineering design had a positive perception by the general public (Wicklein, 2004). Major stakeholders in the educational environment including administrators, teachers, parents, and students need to be able to clearly identify the goals and major activities associated with technology education. Incorporating engineering design into technology education and clearly articulating the learning outcomes, class activities, and related career opportunities could serve to improve the public perception of the field and thus alleviate many of the image problems that exist.

Another conclusion to be drawn from this study is that integrating engineering design concepts into technology education classes could provide increased rigor as students apply academic skills and knowledge to technological problems. Career, technical, and agriculture education teachers are being encouraged to provide increased rigor in the curriculum and to emphasize the application of academic content where possible. Given this context, technology education would benefit greatly from the development of an engineering design focused

curriculum that features a logical progression in course content from elemental skills in introductory classes to advanced work involving the integration of concepts from mathematics and science in upper-level classes.

#### Conclusions from Delphi Results

A first and major conclusion to be made from the Delphi research process carried out as part of this research is that engineering design is a possible curriculum component for technology education courses that are specifically designed and reworked to incorporate this content area. Participants in this study were able to identify and indicate a high level of agreement with 48 items that should be included in a technology education curriculum that emphasizes engineering design. This finding gives a strong indication that engineering design can in fact be considered as a potential contributor to the field of technology education. Professionals in the field of technology education should look seriously at the benefits of infusing the curriculum with content and methodology from the field of engineering design. It is therefore incumbent upon current technology teachers to seek out ways to educate themselves about engineering design and to seek out opportunities to learn more about an engineering design focused curriculum through professional development, additional coursework, etc.

A second conclusion that can be made from the results of the Delphi study is that since survey items such as problem identification, solving open-ended problems, generating multiple solutions to a problem, the ability to synthesize, and systems thinking received the highest scores overall, an engineering design focused curriculum should emphasize these broad concepts. These findings have strong correlation to the *Standards for Technological Literacy* (ITEA, 2000) and other literature in the field that emphasizes problem solving and the ability to think broadly in the context of solving technological problems. This type of curriculum would be in direct contrast to a more structured pedagogy that demands rote memory work without a great deal of higher-order thinking.

An important consideration at this juncture is the current educational climate of accountability in which secondary technology education programs exist. Technology teachers

should clearly communicate the goals of their curriculum and the strategies employed so that parents, administrators, and counselors are aware of the traditionally academic content students make use of in technology education classrooms while solving technological problems. This can best be done through requiring students to carefully document and communicate their design process to others. This documentation work can be in the form of background research, written descriptions, hand sketches, computer-aided drawing (including 3D models), mathematical models, etc. Students should be required to develop potential solutions in the planning stages through careful calculation and modeling rather than through trial and error with actual components. Thus, teachers can display examples of student work so that stakeholders in the community can be made aware of the scope and nature of the technology education curriculum.

A third conclusion is that various means of communication should also be emphasized since items that dealt with several different forms of communication also received high scores. Oral, written, and graphical communication all were emphasized by the participants and were deemed an extremely important component of engineering design. This finding again has correlation to literature in the field of technology education which specifically emphasizes the necessity of good communication in a variety of forms (ITEA, 2003). A project-oriented curriculum that emphasizes teamwork and communication would be best suited for teaching the engineering design process.

A fourth conclusion from this study is that an engineering design-focused curriculum should emphasize teamwork and personal ethics. There was a high level of agreement that a secondary level technology education curriculum with an emphasis on engineering design should foster teamwork and interpersonal skills. It should also focus on the ethical responsibility of the designer to his or her fellow human beings. This finding somewhat contrasts with the typical instructional model that emphasizes the individual's responsibility to perform independently on standardized tests. This approach is congruent with the literature in the field (ITEA, 2000; ITEA, 2003) which emphasize the importance of thinking broadly and looking for multiple points of view.

A fifth conclusion that can be drawn from this study is that the emphasis of a secondary-level program should be on solving problems rather than on teaching specific math/science concepts to be applied at some time in the future. This conclusion was evident because of some of the comments made by participants and also because of the very general nature of the responses to Questions Two and Three. At the outset of this study, it was thought that participants would identify many specific aspects of the various branches of mathematics and science that are especially useful in design situations. However, participants focused on general topics such as algebra, geometry, etc. rather than providing detailed explanation of what specifically was most applicable from that area. The emphasis seemed to be on structuring the curriculum so that students were required to make use of a wide range of knowledge in order to solve problems.

This wide range of subject matter that may be encountered in the course of solving technological problems is a very beneficial development because it naturally fosters interdisciplinary instruction. Technology education teachers should seek out their colleagues in the disciplines of mathematics and science in order to collaborate on subject matter that might be unfamiliar. Collaboration with teachers from other disciplines can broaden the depth of the content for students, enrich the teachers understanding of the related subject matter, and provide a more positive problem solving experience.

A sixth conclusion from this study is that an engineering design-focused curriculum should include a hands-on component because prototyping/fabrication skills received high scores, as did product dissection. This finding fits well with typical technology education practice. In a time when the hands-on component of the curriculum has been de-emphasized in some circles, this result was strong evidence that such training has an important place in the curriculum. Activities that emphasize modeling, fabrication, etc. tend to be higher interest for students and would help to create a contextual learning environment that would encourage students to truly apply academic skills and knowledge in the process of creating solutions to technological problems. Carefully structured activities can be of high interest to students while requiring use of many of the mental processes (Halpin, 1973; Wicklein & Rojewski, 1999), related

academic content, and concepts from engineering design. This type of learning environment would be greatly beneficial to students and would follow established contextual learning models (Parnell, 1995).

## Recommendations

After completing this study and compiling the results, some recommendations can be made. These recommendations fall into three categories: future research, technology education instructional delivery methods, and teacher preparation.

### Recommendations for Future Research

1. Although this study sought to make a contribution to the development of a curriculum framework to be used in the delivery of course content in the area of technology education, further research is needed. There are specific aspects of using engineering design as a curriculum organizer that need to be addressed in order for the knowledge-base in this area to be complete enough to make this framework a reality. They are listed below:

a. Academic content

One of the issues to be addressed involves the general nature of the responses to the research questions in this study. Although the participants identified some general areas from mathematics and science that should be included in an engineering design-based curriculum, additional work needs to be done to determine what specific concepts from these areas are most applicable in the context of solving technological problems in technology education classes. For instance, algebra and geometry received high scores, but few specific concepts within these areas were identified. Further research should be done to determine what specific topics within these content areas are most applicable in the context of an engineering design-based curriculum.

b. Pedagogy

Another area needing future research involves the development of instructional methods designed to address the items identified as very important in the study. Since items such as solving open-ended problems, teamwork, and communication scored highly,

additional research is needed to determine how to best structure the curriculum in order to emphasize these skills. The literature has a good deal of information regarding many of these areas; however, more specific work should be done related to incorporate these specific concepts and skills from engineering design into the technology education curriculum.

2. This study needs to be expanded by incorporating input from other engineering disciplines into the curriculum framework. Each participant in this research had a mechanical engineering background; additional studies might focus on other areas. Some engineering disciplines might be more suited to inclusion in this process than others are. Also, it would be beneficial to include more female and minority participants in future studies.

#### Technology Education Instructional Delivery Methods

3. The field should adopt a more unified approach centered on the topic of engineering design. As stated earlier, there are several approaches to the delivery of curriculum content currently practiced in technology education classrooms across the country.. This does not mean that each class would be in lock-step sequence throughout the year, but rather that each program would use engineering design as its curriculum organizer. This one step would solve many of the issues facing the field and bring much needed direction to many who question the scope and purpose of technology education programs.
4. The field of technology education should embrace content and concepts from engineering design. Classroom teachers should take the necessary steps to prepare themselves to integrate engineering design into their current curriculum. The results of the literature review completed for this study show that engineering design is similar in nature to the goals and intent of the *Standards for Technological Literacy* (ITEA, 2000). Many of the highest ranking items in this Delphi study are also important concepts in the *Standards*. Embracing concepts from engineering design and incorporating them into technology education courses could be a very positive development for the field.

## Teacher Preparation

This study has implications for teacher preparation institutions. Since many are currently looking to engineering design as a curriculum organizer and funding has been appropriated to form the NCETE, it would be beneficial for all programs that prepare technology education teachers to be aware of this development and take steps to prepare their students. This preparation involves at least three things: understanding of the engineering design process, developing the ability to facilitate classroom projects that enable students to engage in engineering design, and gaining the necessary academic skills to do so.

5. The nature of engineering design could perhaps best be communicated to future teachers through requiring them to participate in classroom activities that emphasize engineering design. In other words, the projects would involve many of the items identified in this study. College students preparing to be technology teachers should be exposed to activities that involve open-ended problems, teamwork, and good communication using a variety of methods. Students should be required to use appropriate levels of mathematics and science in order to arrive at their solutions. In this way, future teachers of technology education will see the instructional method modeled before graduation and even be able to replicate some of the projects with their own students.
6. Teacher preparation institutions should require their graduates to take appropriate mathematics and science courses. Some of these should come from the science and mathematics departments and others from technology education instructors. The latter should be focused on helping future technology teachers gain skills in applying mathematics and science in the context of various technological problem-solving activities.
7. Teacher preparation institutions should make sure that faculty members are aware of the scope and nature of engineering design. This recommendation does not mean a total shift from the status quo. It does mean a greater awareness of engineering and, more specifically, a greater understanding of the engineering design process so that this aspect can be communicated to post-secondary students who are going into the classroom.

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APPENDIX A

Letter to Dr. Clive Dym

College of Education  
Workforce Education, Leadership, and Social Foundations

Dr. Clive L. Dym  
Harvey Mudd College  
301 Platt Boulevard  
Claremont, CA 91711

Dear Dr. Dym:

My doctoral advisor, Dr. Robert Wicklein, has suggested that I contact you to request your help in establishing a pool of professors that may serve as experts in the field of engineering design for my doctoral research. If you agree to participate, you will be asked to identify the names and mailing addresses of 10 persons you feel are qualified as experts in the field of engineering design. These persons you identify will be asked to in-turn identify 10 individuals qualified to participate in the study. From this list, we will select approximately 25 participants for this study.

My study is titled **Engineering Design in Secondary Technology Education**. The results of this study will help educators in the field of Technology Education develop a secondary curriculum that emphasizes the engineering design process. Many high schools across the country currently offer a program of study called Technology Education. Instruction typically centers on helping students achieve technological literacy through problem solving and design activities that utilize the technological problem solving method. Leaders in the field have recognized that the engineering design process incorporates and concisely expresses many facets of what technology education seeks to equip students to do. However, there are many questions to be answered and this study seeks to contribute to the growing body of literature on the subject of how the engineering design process can be matriculated in the secondary technology education curriculum.

You have been identified as my initial point of contact because of your extensive background and knowledge in engineering design and your highly respected international reputation. As you can see, the beginning of this entire study relies on your participation! I hope this does not assume too much, but we feel that your reputation and work with the Mudd Design Conference uniquely positions you to identify top experts in this field.

This study will rely on the Delphi technique in order to elicit the responses of a geographically dispersed group in an anonymous and efficient manner. The study will be conducted in a series of four rounds – the online survey for each round should take less than 30 minutes to complete. Participants will access the study website and complete the survey one time for each successive round.

Thank you for considering being involved in this study and we would ask that you please **email the names and addresses of the 10 experts** to me at the address below. If you are not able to do this at this time please advise me of this as well. I will be happy to answer any questions you might have- I hope to hear from you very soon!

APPENDIX B

Initial Contact Email

Hello, as part of my doctoral study at the University of Georgia, I recently asked Dr. Clive Dym at Harvey Mudd College to name 12 persons he considered to be experts in the field of engineering design. You were one of those 12 - therefore I am contacting you at this time to ask you for the names of 12 persons that you feel are experts in the field of engineering design. My goal is to create a large pool of possible participants for my Delphi study. This study is related to developing a curriculum that emphasizes engineering design for students at the secondary level. If you will be so kind as to supply the name, school or company, and email address of 12 individuals you feel would be very qualified to participate in this study it would be greatly appreciated and make progress possible. Your recommendation in no way obligates your colleagues! The study itself will be conducted via the Internet and will consist of 4 rounds of around 30 minutes each.

Dr. Dym does not automatically assume you will have time to supply the list of names, but he does feel that you are qualified. This is a crucial step in my study and I can not go forward until I gain this list. I can supply more details about the logistics of the study on request and feel free to contact me if you have any questions. Thank you for your consideration!

Cameron Smith  
Doctoral Candidate  
University of Georgia

APPENDIX C

Round 1 Survey

## Round 1 Survey

1. What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems?
2. What mathematics concepts related to engineering design should secondary students use to understand, manage, and solve technological problems?
3. What specific science principles related to engineering design should secondary students use to understand, manage, and solve technological problems?
4. What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage, and solve technological problems?

APPENDIX D

Round 1 Results - by Participant

### Participant 'A'

Q1. Understanding the problem, understanding customer needs, brainstorming solutions You can get pretty far with algebra for a number of problems (statics, some fluids, etc.

Q2. Should understand conservation of energy and momentum, conversion of energy to different types (potential, kinetic, etc.) Force equilibrium for static problems,  $F = ma$

Q3. Identifying the underlying scientific principles governing a problem, Basic physics

Q4. Learning how to find specialized knowledge. Understanding how to set up a program of experiments and evaluate results Brainstorming skills to determine lots of concepts Communication skills Shop fabrication (or access to such skills) drawing skills (possibly CAD skills)

### Participant 'B'

Q1. 1.. Ability to think about open ended, ill-defined problems. Much of secondary school math/science education focuses on solving problems to get a single right answer, and engineering design process helps them think more broadly. 2. Need to synthesize different types of knowledge. Engineering design process encourages individuals to draw upon different types of knowledge all at once, rather than one discipline.

Q2. Secondary students need to know be familiar with basic engineering math, which means algebra and geometry, and if possible, calculus.

Q3. Basic physics is important, in particular introductory mechanics.

Q4. The process of generating ideas, prototyping them, and testing them is key in doing engineering design at any level. For secondary school students, this might require teaching students some prototyping skills (freehand drawing, building ideas in soft materials, or working with simple hand- or even machine-tools).

### Participant 'C'

Q1. Identifying a need, requirements list, conceptual design, computer-aided modeling

Q2. calculus, algebra, linear algebra, statistics

Q3. physics, chemistry, biology

Q4. problem solving, idea generation, CAD, prototyping, computer programming



### Participant 'D'

Q1. Physics based approaches based on conservation laws

Q2. Optimization - particularly evolutionary optimization In-Out = change on a integral basis

Q3. summation of forces = mass x acceleration

Q4. A strong command of algebra, and an ability to use common engineering software tools.

### Participant 'E'

Q1. recognition and formulation of design problems, generate potential design alternative  
evaluation of alternatives data collection and interpretation decision making

Q2. measurement theory optimization statistics probability

Q3. science principles rooted in the above mathematics concepts Understand the problem  
formulate a problem generate design concepts provide mathematical descriptions of design  
solutions

Q4. Search design solution using efficient computer algorithms design experiments and analyze  
data apply decision making principles communication team work synthesis dealing with open-  
ended problems

### Participant 'F'

Q1. open-ended problem solving, working prototype construction, use of basic physics,  
chemistry, math applied to analysis of a design situation

Q2. algebra, statistics, simple programming

Q3. physics: particularly mechanics, simple circuit analysis chemistry: as it relates to material  
properties and manufacturing possibilities

Q4. The key idea of the engineering method that you must solve a problem in the face of  
incomplete information; be able to abstract the real problem to an appropriate level of abstraction  
so you can apply useful analysis from physics etc. This issue is the biggest problem students  
face all the way to finishing their Ph.D.s.

### Participant 'G'

Q1. The simple answer is all of them (this is too open a question). Some specifics include:  
Problem identification. Understanding the customer wants.

Q2. Writing a quantitative specification. Too broad a question. Algebra, trigonometry, pre-  
calculus

Q3. Too broad a question. It depends on the problem being solved: physics, chemistry, biology, mathematics.

Q4. Too broad a question. Drafting, machining, wood shop.

#### Participant 'H'

Q1. Brainstorming; intuition; hands-on experience dissecting products, etc.; critical thinking skills; project planning skills; good oral and written communication skills; artistic talent/sketching ability; ability to reason and debate good and bad merits of a design concept.

Q2. This is somewhat problem-dependent: some problems require little to no math while others require complex analysis using matrices, differential equations, etc. I think what is more critical is knowing how to set up, mathematically model, and formulate the problem at hand and then knowing what math skills are needed - and where to find, say, relevant equations - to solve the problem.

Q3. Same thing as with math skills, i.e., very problem-dependent. Some problems require simple laws like  $F=ma$  while others are much more complex (e.g., laws of fluid flow, thermodynamics, etc.). Again, what is important is being able to reason critically about the problem to identify what types of principles are needed and then knowing where to find them.

Q4. Same answer as Q1.

#### Participant 'I'

Q1. to know there is a process and understand the major steps and tools available and used in industry.

Q2. To experience them doing a project - not garage engineering.

Q3. There is virtually no math needed. If anything a good basis of statistics as all design is uncertain

Q4. Design process is not science. Engineering analysis is based on science and is a necessary part of the design process. QFD, Pugh's method, FMEA, and all the rest I cover in "The Mechanical Design Process"

#### Participant 'J'

Q1. Logical thinking.

Q2. Logical thinking.

Q3. Mathematics (just fundamental algebra and geometry),

Q4. physics (I guess I am biased toward machine design).  
Logical thinking, a bit of commonsense.

Participant 'K'

Q1. Within the scope of secondary school education: \* Understanding requirements of problem in context \* Working as a goal-oriented team, making best use of resources/talent \* Developing multiple concepts for meeting specified requirements \* Selection of most appropriate concept within overall context \* Developing chosen concept into a practicable solution \* Presenting the solution in a convincing manner

Q2. Some mathematical concepts useful for underpinning student interaction with technological problems: \* The concept of dealing with approximations rather than exact numbers \* The concept of finding solutions without all the necessary information \* The concept of mapping alternatives in different ways \* The concept of statistical exploration of life-cycle issues

Q3. Some scientific “principles” important to understand as an underpinning to the solution of technological problems: \* Force and deflection - visualization of force transmission paths \* Stress and distortion - visualization of material capabilities \* Expansion and contraction - thermal effects on materials \* Heat transfer - conduction, convection and radiation \* Energy conversion - mass balance \* Static pressure and fluid flow - visualization and general concepts \* Basics of electrical power theory and electronic controls

Q4. Some skills, techniques and engineering tools that could be useful in the context of encouraging students to increase their technology involvement: \* Genuine understanding of personal capabilities and limitations \* Enthusiasm and respect for historical/prior technological developments \* Excellence in negotiation and communication - both oral and written \* High degree of cross-cultural understanding and multiple language skills \* Understanding of ethical issues and effects of external influences \* Ability to visualize and describe problems in diagrammatic form \* Effective use of knowledge and resources to finish a task completely

Participant 'L'

Q1. Understand: Identification for problem via function structures. Manage: Creation of a work schedule Solve: Recognition that the solution method depends on the type of problem at hand.

Q2. Physics

Q3. This is too broad a question to elicit a meaningful response. In general principles of conservation of mass and energy; Newton's laws

Q4. Ability to abstract, Ability to analyze. Ability to synthesize. Ability to evaluate design so that it can be improved.

Participant 'M'

Q1. Ability to break down complex problems in manageable pieces. Synthesis of simple parts into more complex system. First hand learning and experience of how products, parts, and engineered systems in general work (and fail). Teamwork.

Q2. Integration, differentiation, algebra (solving systems of equations), trigonometry. Numerical problem solving using computers and spreadsheets.

Q3. Energy principles (potential, kinetic, heat, etc). Newton's Laws: Forces, reactions, velocity & acceleration. Some basic strength, strain & stress principles (tension, compression, shear, torsion - what is it & what can it do)

Q4. Some basic material selection principles (steel vs iron vs aluminum vs plastic, etc). Some basic understanding of standard components (what is a roller bearing, gear, shaft, electromotor, etc)

Good general computer skills (word processing, presentation, e-mail). Especially well versed in using spreadsheets, including graphing. Good research skills (how to find info on something you don't know much about and document your findings), using Internet/web, library, personal contacts/sources. Teamwork, planning, and meeting skills. Some solid modeling CAD skills to show the final product, e.g., using SolidEdge (do NOT use AutoCAD - that is outdated for most engineers, except civil engineers).

#### Participant 'N'

Q1. Aspects include innovative concept generation, functional modeling, customer needs gathering and problem clarification, and product modeling.

Q2. Concepts include analytical geometry, trigonometry, advanced algebra, and basic calculus and differential equations.

Q3. General principles include robustness, clarity (functional independence), simplicity (minimal information content), and safety (human factors). More specific principles are the Theory of Inventive Problem Solving Laws of Evolution and Design Principles.

Q4. Skills: Problem Solving, problem reformulation, fabrication in various materials, modeling of physical systems; Techniques: Analogical Reasoning, functional modeling, quality function deployment, team-based synthesis (such as 6-3-5).

#### Participant 'O'

Q1. Understanding context, managing ambiguity, identifying needs, constructing requirements, scientific experimentation and prototyping, defining and refining intent, systems thinking.

Q2. Probability, statistics, numerical simulation, and the obvious basic engineering math such as calculus and linear algebra.

Q3. Basic understanding of dynamic systems, circuits, strength of materials, thermodynamics, decision analysis, cognitive science, learning theories.

Q4. CAD tools (visual and numerical), sketching, prototyping and manufacturing methods, ethnography (qualitative observation of people/users), communication (as in interacting with users/team members and presenting/documenting work), negotiation.

APPENDIX E

Round 2 Survey

## Round Two Survey

What is your Respondent ID number? \_\_\_\_\_

The following 38 items are responses to Question 1: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems? For each item, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum which is designed to equip secondary (high school) students to understand, manage, and solve technological problems.

### 1. Understand problem identification / formulation / development of requirements lists

- Strongly Disagree
- Disagree
- Somewhat Disagree
- Somewhat Agree
- Agree
- Strongly Agree

### 2. Understand functional structures

- Strongly Disagree
- Disagree
- Somewhat Disagree

Note – the remaining items in this survey instrument have the Likert scale removed to make this document more readable.

3. Understanding of customer needs
4. Project planning and scheduling
5. Teamwork
6. Decision making methodologies
7. Written communication
8. Oral communication
9. Graphical/pictorial communication
10. Negotiation
11. Meeting skills
12. Personal ethics
13. Multicultural/diversity awareness
14. Ability to break down complex problems in manageable pieces
15. Ability to handle open-ended/ill-defined problems
16. Ability to integrate multiple domains of knowledge
17. Acceptance of multiple solutions to a single problem
18. Brainstorming and innovative concept generation
19. Conceptual design
20. Design for robustness/failure mode analysis
21. Engineering heuristics for/analysis-based design
22. Experimental design, data collection, and interpretation of results
23. Functional product modeling
24. Human factors and safety in design
25. Identification of good/bad design
26. Identification of underlying scientific principles
27. Product optimization
28. Product testing/functional analysis
29. Prototyping/fabrication skills
30. Recognition that the solution method depends on the type of problem at hand
31. Research/library skills
32. Simplicity and clarity of use and function
33. Synthesis of simple parts into more complex system.
34. Understanding product life cycles/life cycle analysis
35. Critical thinking
36. Experience
37. Logic and logical thinking
38. Systems thinking
39. Can you list other aspects of the engineering design process that would best equip secondary students to understand, manage, and solve technological problems?

The next 18 items are responses to Question 2: What mathematics concepts related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum designed to require secondary (high school) students to use various mathematical concepts to understand, manage, and solve technological problems.

40. Basic Algebra
41. Advanced Algebra
42. Linear Algebra
43. Geometry
44. Trigonometry
45. Pre-Calculus
46. Statistics
47. Calculus- Integration
48. Calculus- Differentiation
49. Calculus- Differential Equations
50. Measurement theory
51. Approximation
52. Ability to handle open-ended/ill-defined problems
53. Multiple solutions to a single problem
54. Optimization
55. Computer Programming
56. Spreadsheets
57. Modeling/simulation/numerical analysis software
58. Can you provide specific formulas or specific mathematics concepts commonly used in engineering design that would be useful for secondary (high school) students involved in understanding, managing, and solving technological problems?

The next 20 items are responses to Question 3: What specific science principles related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum designed to require secondary (high school) students to use various scientific principles to understand, manage, and solve technological problems.

59. Chemical properties of materials
60. Effects of chemical formulation on manufacturing
61. Biological Evolution
62. Conservation of mass, energy, and momentum
63. Dynamic systems
64. Introductory mechanics
65. Newton's laws: forces, reactions, velocity & acceleration
66. Summation of forces/force equilibrium
67. Types of energy



68. Circuit analysis and electrical power
69. Control theory
70. Fluid flow
71. Heat and mass balances
72. Heat transfer
73. Statics
74. Strength of materials
75. Thermodynamics
76. Decision analysis
77. Cognitive science
78. Learning theories
79. Can you provide other scientific principles that should be emphasized in an engineering design focused curriculum that involves secondary (high school) students in understanding, managing, and solving technological problems?

The next 13 items are responses to Question 4: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum designed to require secondary (high school) students to use various skills, techniques, and engineering tools to understand, manage, and solve technological problems.

80. Computer aided design software
81. Computer searching
82. E-mail
83. Plotting Software
84. Presentation software
85. Ability to abstract
86. Ability to synthesize
87. Analogical reasoning
88. Historical perspective
89. Analysis-based design
90. Basic mechanical mechanisms
91. Failure mode and effects analysis
92. Product Dissection
93. Can you list additional skills, techniques, or engineering tools related to engineering design that secondary (high school) students should use to understand, manage, and solve technological problems?

APPENDIX F

Round 3 Survey

Thank you for your participation thus far in the Engineering Design in Technology Education study! As you know, Rounds One and Two are complete and I have been compiling all the responses and preparing Round Three. This has taken quite a bit of time and was more of a challenge than I anticipated! In preparation for beginning Round Three, I am sending out this instructional email – I will send another email later today that contains the link to the Round Three survey. Please note the following three items:

1. This study is designed to help in the creation of a framework for a curriculum which emphasizes engineering design for high school students. Please keep in mind the level of math/science courses in which high school students are normally enrolled (a small minority of students may take Calculus during the 12<sup>th</sup> grade; a larger number may have Physics during the 11<sup>th</sup> or 12 grade).
2. There are comment blanks at the end of each section. Please take a moment to consider any specific answers that come to mind. These would be more helpful to actually creating a curriculum framework than more general topics such as algebra, etc.
3. This study is utilizing the Delphi method. This method dictates that in Round Three participants be given the Round Two survey items again - along with statistical data which indicates the group response to each item. I acknowledge that this seems redundant. However, if you will bear with the process, the goal is to give you an opportunity to consider your choices again in light of the statistical data. This may lead to a change in your answers from Round Two or it may not. To assist you in this process I have attached an Excel file to this email with your responses to the Round Two items. Please let me know if you have trouble opening the file.

Again, thank you very much for making this study possible!  
Cameron Smith

APPENDIX G  
Round 3 Survey Instrument

What is your Respondent ID number? \_\_\_\_\_

The following section consists of responses to Question 1: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems? For each item, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum which is designed to equip secondary (high school) students to understand, manage, and solve technological problems. \*The Round Two data is included with each question. Please make note of whether your answer falls outside the Interquartile Range (IQR) or middle 50%. If it does, please feel free to comment as to why you made this choice in the comments box at the end of this survey.

1. Understand problem identification / formulation / development of requirements lists  
(Round Two Data: Mean= 5.85, Max=6, Min=5, St. Dev.= 0.3755, IQR= 6)

- Strongly Disagree (1)
- Disagree (2)
- Somewhat Disagree (3)
- Somewhat Agree (4)
- Agree (5)
- Strongly Agree (6)

2. Understand functional structures (Round Two Data: Mean= 4.77, Max=6, Min=2, St. Dev.= 1.3634, IQR= 4-6)

- Strongly Disagree (1)
- Disagree (2)
- Somewhat Disagree (3)
- Somewhat Agree (4)
- Agree (5)
- Strongly Agree (6)

Note – the additional items from the Round Three survey instrument are displayed here without the associated Likert scale to make this document more readable.

3. Understanding of customer needs (Round Two Data: Mean= 5.31, Max=6, Min=3, St. Dev.= 0.8549, IQR= 5-6)
4. Project planning and scheduling (Round Two Data: Mean= 4.92, Max=6, Min=4, St. Dev.= 0.7596, IQR= 4-5)
5. Teamwork (Round Two Data: Mean= 5.23, Max=6, Min=4, St. Dev.= 0.5991, IQR= 5-6)
6. Decision making methodologies (Round Two Data: Mean= 4.62, Max=6, Min=3, St. Dev.= 0.1.0439, IQR= 4-5)
7. Written communication (Round Two Data: Mean= 5.23, Max=6, Min=4, St. Dev.= 0.8321, IQR= 5-6)
8. Oral communication (Round Two Data: Mean= 5.54, Max=6, Min=5, St. Dev.= 0.5189, IQR= 5-6)
9. Graphical/pictorial communication (Round Two Data: Mean= 5.23, Max=6, Min=4, St. Dev.= 0.7250, IQR= 5-6)
10. Negotiation (Round Two Data: Mean= 4.15, Max=6, Min=3, St. Dev.= 0.8006, IQR= 4)
11. Meeting skills (Round Two Data: Mean= 4.54, Max=6, Min=4, St. Dev.= 0.6602, IQR= 4-5)
12. Personal ethics (Round Two Data: Mean= 5.00, Max=6, Min=4, St. Dev.= 0.7071, IQR= 5)
13. Multicultural/diversity awareness (Round Two Data: Mean= 4.38, Max=6, Min=2, St. Dev.= 1.2609, IQR= 4-5)
14. Ability to break down complex problems in manageable pieces (Round Two Data: Mean= 5.00, Max=6, Min=4, St. Dev.= 0.8165, IQR= 4-6)
15. Ability to handle open-ended/ill defined problems (Round Two Data: Mean= 5.46, Max=6, Min=4, St. Dev.= 0.6602, IQR= 5-6)
16. Ability to integrate multiple domains of knowledge (Round Two Data: Mean= 5.31, Max=6, Min=3, St. Dev.= 0.9473, IQR= 5-6)
17. Acceptance of multiple solutions to a single problem (Round Two Data: Mean= 5.62, Max=6, Min=5, St. Dev.= 0.5064, IQR= 5-6)
18. Brainstorming and innovative concept generation (Round Two Data: Mean= 5.00, Max=6, Min=4, St. Dev.= 0.5774, IQR= 5)
19. Conceptual design (Round Two Data: Mean= 5.42, Max=6, Min=5, St. Dev.= 0.5149, IQR= 5-6)
20. Design for robustness/failure mode analysis (Round Two Data: Mean= 3.85, Max=5, Min=1, St. Dev.= 1.0682, IQR= 4)
21. Engineering heuristics for/analysis-based design (Round Two Data: Mean= 3.92, Max=6, Min=5, St. Dev.= 1.3790, IQR= 3.75-5)
22. Experimental design, data collection, and interpretation of results (Round Two Data: Mean= 4.46, Max=6, Min=3, St. Dev.= 0.7763, IQR= 4-5)
23. Functional product modeling (Round Two Data: Mean= 4.31, Max=6, Min=3, St. Dev.= 0.8549, IQR= 4-5)

24. Human factors and safety in design (Round Two Data: Mean= 4.54, Max=5, Min=4, St. Dev.= 0.5189, IQR= 4-5)
25. Identification of good/bad design (Round Two Data: Mean= 4.77, Max=6, Min=4, St. Dev.= 0.7250, IQR= 4-5)
26. Identification of underlying scientific principles (Round Two Data: Mean= 4.77, Max=6, Min=3, St. Dev.= 0.8321, IQR= 4-5)
27. Product optimization (Round Two Data: Mean= 3.54, Max=5, Min=2, St. Dev.= 0.8771, IQR= 3-4)
28. Product testing/functional analysis (Round Two Data: Mean=4.46 , Max=6, Min=3, St. Dev.=0.8771 , IQR=4-5)
29. Prototyping/fabrication skills (Round Two Data: Mean=4.85 , Max=6, Min=4, St. Dev.=0.8006 , IQR=4-5)
30. Recognition that the solution method depends on the type of problem at hand (Round Two Data: Mean=4.31 , Max=6, Min=3, St. Dev.=0.8549 , IQR=4-5)
31. Research/library skills (Round Two Data: Mean=4.62 , Max=6, Min=2, St. Dev.=1.0439 , IQR=4-5)
32. Simplicity and clarity of use and function (Round Two Data: Mean=4.54 , Max=6, Min=4, St. Dev.=0.6602 , IQR=4-5)
33. Synthesis of simple parts into more complex system. (Round Two Data: Mean=4.54 , Max=6, Min=3, St. Dev.=0.7763 , IQR=4-5)
34. Understanding product life cycles/life cycle analysis (Round Two Data: Mean=4.38 , Max=6, Min=3, St. Dev.=0.7679 , IQR=4-5)
35. Critical thinking (Round Two Data: Mean=5.23 , Max=6, Min=4, St. Dev.=.08321 , IQR=5-6)
36. Experience (Round Two Data: Mean=4.00 , Max=6, Min=2, St. Dev.=1.2910 , IQR=3-5)
37. Logic and logical thinking (Round Two Data: Mean=4.92 , Max=6, Min=4, St. Dev.=0.6405 , IQR=5)
38. Systems thinking (Round Two Data: Mean=5.31 , Max=6, Min=4, St. Dev.=0.8549 , IQR=5-6)
39. Can you list other aspects of the engineering design process that would best equip secondary students to understand, manage, and solve technological problems?
- 39a. Costing, profit, and basic economic analysis (new item, no Round Two data)
- 39b. Understanding the context of the technological problem and possible external influences (new item, no Round Two data)
- 39c. Product architecture and modularity/interfaces (new item, no Round Two data)
- 39d. Design principles to assist in generating innovative concepts (new item, no Round Two data)
- 39e. Design by analogy (new item, no Round Two data)

The next section consists of responses to Question 2: What mathematics concepts related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused

curriculum designed to require secondary (high school) students to use various mathematical concepts to understand, manage, and solve technological problems. \*The Round Two data is included with each question. Please make note of whether your answer falls outside the Interquartile Range (IQR) or middle 50%. If it does, please feel free to comment as to why you made this choice in the comments box at the end of this survey.

40. Basic Algebra (Round Two Data: Mean=5.38 , Max=6, Min=4, St. Dev.=0.7679 , IQR=5-6)
41. Advanced Algebra (Round Two Data: Mean=4.85 , Max=6, Min=2, St. Dev.=1.1435 , IQR=4-6)
42. Linear Algebra (Round Two Data: Mean=4.00 , Max=5, Min=2, St. Dev.=1.0000 , IQR=3-5)
43. Geometry (Round Two Data: Mean=5.15 , Max=6, Min=4, St. Dev.=0.6887 , IQR=5-6)
44. Trigonometry (Round Two Data: Mean=5.17 , Max=6, Min=4, St. Dev.=0.7177 , IQR=5-6)
45. Pre-Calculus (Round Two Data: Mean=4.75 , Max=6, Min=4, St. Dev.=0.6216 , IQR=4-5)
46. Statistics (Round Two Data: Mean=4.85 , Max=6, Min=4, St. Dev.=0.8987 , IQR=4-6)
47. Calculus- Integration (Round Two Data: Mean=4.62 , Max=6, Min=3, St. Dev.=.9608 , IQR=4-5)
48. Calculus- Differentiation (Round Two Data: Mean=4.62 , Max=6, Min=3, St. Dev.=.9608 , IQR=4-5)
49. Calculus- Differential Equations (Round Two Data: Mean=3.92 , Max=5, Min=2, St. Dev.=0.7596 , IQR=4)
50. Measurement theory (Round Two Data: Mean=4.23 , Max=6, Min=3, St. Dev.=0.7250 , IQR=4)
51. Approximation (Round Two Data: Mean=5.08 , Max=6, Min=3, St. Dev.=1.0377 , IQR=4-6)
52. Ability to handle open-ended/ill defined problems (Round Two Data: Mean=5.62 , Max=6, Min=4, St. Dev.=0.6504 , IQR=5-6)
53. Multiple solutions to a single problem (Round Two Data: Mean=5.46 , Max=6, Min=4, St. Dev.=.6602 , IQR=5-6)
54. Optimization (Round Two Data: Mean=3.31 , Max=5, Min=1, St. Dev.=1.1094 , IQR=3-4)
55. Computer Programming (Round Two Data: Mean=4.23 , Max=6, Min=2, St. Dev.=1.0919 , IQR=4-5)
56. Spreadsheets (Round Two Data: Mean=5.15 , Max=6, Min=4, St. Dev.=0.8006 , IQR=5-6)
57. Modeling/simulation/numerical analysis software (Round Two Data: Mean=4.46 , Max=6, Min=3, St. Dev.=0.9674 , IQR=4-5)
58. Can you provide specific formulas or specific mathematics concepts commonly used in engineering design that would be useful for secondary (high school) students involved in understanding, managing, and solving technological problems?



- 58a. Algebraic equations for determining gear ratios (new item, no Round Two data)
- 58b. Conservation of momentum (new item, no Round Two data)
- 58c. Projectile motion (new item, no Round Two data)
- 58d. Structural equilibrium (new item, no Round Two data)
- 58c. Basic stresses (new item, no Round Two data)

The next section consists of responses to Question 3: What specific science principles related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum designed to require secondary (high school) students to use various scientific principles to understand, manage, and solve technological problems. \*The Round Two data is included with each question. Please make note of whether your answer falls outside the Interquartile Range (IQR) or middle 50%. If it does, please feel free to comment as to why you made this choice in the comments box at the end of this survey.

- 59. Chemical properties of materials (Round Two Data: Mean=4.17 , Max=5, Min=3, St. Dev.=0.5774 , IQR=4-4.25)
- 60. Effects of chemical formulation on manufacturing (Round Two Data: Mean=3.38 , Max=5, Min=2, St. Dev.=1.0439 , IQR=3-4)
- 61. Biological Evolution (Round Two Data: Mean=3.31 , Max=6, Min=1, St. Dev.=1.3775 , IQR=2-4)
- 62. Conservation of mass, energy, and momentum (no Round Two data available)
- 63. Dynamic systems (Round Two Data: Mean=4.23 , Max=5, Min=3, St. Dev.=0.5991 , IQR=4-5)
- 64. Introductory mechanics (Round Two Data: Mean=4.77 , Max=6, Min=4, St. Dev.=0.7250, IQR=4-5)
- 65. Newton's laws: forces, reactions, velocity & acceleration (Round Two Data: Mean=5.31 , Max=6, Min=4, St. Dev.=0.6304 , IQR=5-6)
- 66. Summation of forces/force equilibrium (Round Two Data: Mean= 5.08 , Max=6, Min=4, St. Dev.=0.6405 , IQR=5)
- 67. Types of energy (Round Two Data: Mean=5.23 , Max=6, Min=4, St. Dev.=0.5991 , IQR=5-6)
- 68. Circuit analysis and electrical power (Round Two Data: Mean=4.08 , Max=5, Min=3, St. Dev.=0.4935 , IQR=4)
- 69. Control theory (Round Two Data: Mean=3.00 , Max=5, Min=2, St. Dev.=1.0000 , IQR=2-4)
- 70. Fluid flow (Round Two Data: Mean=3.77 , Max=5, Min=3, St. Dev.=0.5991 , IQR=3-4)
- 71. Heat and mass balances (Round Two Data: Mean=3.92 , Max=5, Min=3, St. Dev.=0.7596, IQR=3-4)
- 72. Heat transfer (Round Two Data: Mean=4.08 , Max=6, Min=3, St. Dev.=0.7930 , IQR=4)
- 73. Statics (Round Two Data: Mean=5.00 , Max=6, Min=4, St. Dev.=0.7385 , IQR=4.75-5.25)

74. Strength of materials (Round Two Data: Mean=4.69 , Max=6, Min=3, St. Dev.=0.9473 , IQR=4-5)
75. Thermodynamics (Round Two Data: Mean=3.85 , Max=6, Min=2, St. Dev.=1.0682, IQR=3-4)
76. Decision analysis (Round Two Data: Mean=3.77 , Max=6, Min=2, St. Dev.=1.4233 , IQR=3-4)
77. Cognitive science (Round Two Data: Mean=3.62 , Max=6, Min=2, St. Dev.=1.3868 , IQR=2-5)
78. Learning theories (Round Two Data: Mean=3.62 , Max=6, Min=2, St. Dev.=1.5021 , IQR=3-4)
79. Can you provide other scientific principles that should be emphasized in an engineering design focused curriculum that involves secondary (high school) students in understanding, managing, and solving technological problems?
- 79a. Project management (new item, no Round Two data)
- 79b. Thermal expansion/contraction (new item, no Round Two data)

The last section consists of responses to Question 4: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum designed to require secondary (high school) students to use various skills, techniques, and engineering tools to understand, manage, and solve technological problems. \*The Round Two data is included with each question. Please make note of whether your answer falls outside the Interquartile Range (IQR) or middle 50%. If it does, please feel free to comment as to why you made this choice in the comments box at the end of this survey.

80. Computer aided design software (Round Two Data: Mean=4.46 , Max=6, Min=3, St. Dev.=0.8771 , IQR=4-5)
81. Computer searching (Round Two Data: Mean=4.38 , Max=6, Min=2, St. Dev.=1.3253 , IQR=4-5)
82. E-mail (Round Two Data: Mean=4.83 , Max=6, Min=3, St. Dev.=0.8348 , IQR=4.75-5)
83. Plotting Software (Round Two Data: Mean=4.62 , Max=6, Min=3, St. Dev.=0.7679 , IQR=4-5)
84. Presentation software (Round Two Data: Mean=4.85 , Max=6, Min=3, St. Dev.=0.8987 , IQR=4-5)
85. Ability to abstract (Round Two Data: Mean=5.23 , Max=6, Min=4, St. Dev.=0.8321 , IQR=5-6)
86. Ability to synthesize (Round Two Data: Mean=5.69 , Max=6, Min=5, St. Dev.=0.4804 , IQR=5-6)
87. Analogical reasoning (Round Two Data: Mean=5.08 , Max=6, Min=4, St. Dev.=0.6686 , IQR=5-5.25)

88. Historical perspective (Round Two Data: Mean=4.46 , Max=6, Min=4, St. Dev.=0.8771 , IQR=4-5)
89. Analysis-based design (Round Two Data: Mean=4.23 , Max=6, Min=3, St. Dev.=0.9268 , IQR=4)
90. Basic mechanical mechanisms (Round Two Data: Mean=4.23 , Max=5, Min=3, St. Dev.=0.7250 , IQR=4-5)
91. Failure mode and effects analysis (Round Two Data: Mean=3.85 , Max=6, Min=2, St. Dev.=0.9871 , IQR=3-4)
92. Product Dissection (Round Two Data: Mean=5.23 , Max=6, Min=4, St. Dev.=0.5991 , IQR=5-6)
93. Can you list additional skills, techniques, or engineering tools related to engineering design that secondary (high school) students should use to understand, manage, and solve technological problems?
  - 93a. Reverse engineering (new item, no Round Two data)
  - 93b. Finishing job to the last detail (new item, no Round Two data)
  - 93c. Recognizing team roles and personality types (new item, no Round Two data)

If any of your answers in this section fell outside the IQR, please make comments so your colleagues can understand your position. Be sure to include the item number!

APPENDIX H

Round 4 Email

You will be receiving an email from me shortly which will contain a link to the final survey associated with the Engineering Design in Technology Education study! To make this last survey as user friendly as possible, I only included items that had not met the criteria of mean stability and low IQR necessary for completion. Items included in this fourth round were unstable (mean shift of >15% between Rounds Two and Three), had a Round Three IQR>1, or had useful comments given in Round Three. I have attached your individual Round Three answers to this email for you to use when completing the Round Four survey.

Thank you for your patience with this process and your kindness in giving your time to a stranger. I will email a final copy of the results to you in the next few weeks.

APPENDIX I  
Round 4 Survey Instrument

## Round Four Survey

The following section consists of responses to Question 1: What aspects of the engineering design process best equip secondary students to understand, manage, and solve technological problems? For each item, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum which is designed to equip secondary (high school) students to understand, manage, and solve technological problems. \*The Round Three data is included with each question.

2. Understand functional structures (Round Three Data: Mean= 4.00, Max=6, Min=1, St. Dev.= 1.5811, IQR= 4-5)

- Strongly Disagree (1)
- Disagree (2)
- Somewhat Disagree (3)
- Somewhat Agree (4)
- Agree (5)
- Strongly Agree (6)

6. Decision making methodologies (Round Three Data: Mean= 4.58, Max=6, Min=3, St. Dev.= 1.0836, IQR= 4-5.25)

- Strongly Disagree (1)
- Disagree (2)
- Somewhat Disagree (3)
- Somewhat Agree (4)
- Agree (5)
- Strongly Agree (6)

The additional items in the Round Four survey instrument are included here without the Likert scale that was part of the original document as seen by the participants. This was done to make this document more readable.

7. Written communication (Round three data: Mean=5.46, Max=6, Min.=4, Standard Dev.=0.6602, IQR= 5-6) Round Three Comments: We now that informal communication plays an under-recognized role in design team interactions. Although it is highly relevant, formal communication is overemphasized in design/engineering education- maybe because it is easier to teach formal communication practices than informal communication practices.
10. Negotiation (Round Three Data: Mean= 4.46, Max=6, Min=3, St. Dev.= 0.9674, IQR= 4-5) Round Three Comments: There is a large body of evidence that suggests design, among many other things, IS negotiation. Negotiation requires mental flexibility, which is critical for being able to understand and reframe context
13. Multicultural/diversity awareness (Round Three Data: Mean= 4.08, Max=6, Min=2, St. Dev.= 1.1152, IQR= 4) Round Three Comments: If one is to understand and relate to users from diverse backgrounds, and drive his/her design process with that understanding, one must have the highest awareness of multicultural issues.
21. Engineering heuristics for/analysis-based design (Round Three Data: Mean= 3.75, Max=6, Min=1, St. Dev.= 1.3568, IQR= 3-4.25)
26. Identification of underlying scientific principles (Round Three Data: Mean= 4.92, Max=6, Min=4, St. Dev.= 0.8623, IQR= 4-6)
27. Product optimization (Round Three Data: Mean= 3.00, Max=4, Min=1, St. Dev.= 0.8165, IQR= 3)
- 39a. Costing, profit, and basic economic analysis (Round Three Data: Mean= 3.92, Max=5, Min=2, St. Dev.= 0.8623, IQR= 4)
- 39b. Understanding the context of the technological problem and possible external influences (Round Three Data: Mean= 4.77, Max=6, Min=2, St. Dev.= 1.1658, IQR= 5)
- 39c. Product architecture and modularity/interfaces 27. Product optimization (Round Three Data: Mean= 3.92, Max=6, Min=2, St. Dev.= 1.1875, IQR= 3-4)
- 39d. Design principles to assist in generating innovative concepts (Round Three Data: Mean= 4.38, Max=6, Min=3, St. Dev.= 0.9608, IQR= 4-5)
- 39e. Design by analogy (Round Three Data: Mean= 4.00, Max=6, Min=3, St. Dev.= 0.8165, IQR= 4)
- 39f. Understanding basic business motivations for engineering design, such as marketing or consumer research (New item, no round three data)
- 39g. Understanding basic manufacturing processes (New item, no round three data)
- 39h. House of Quality method (New item, no round three data)

The next section consists of responses to Question 2: What mathematics concepts related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused



curriculum designed to require secondary (high school) students to use various mathematical concepts to understand, manage, and solve technological problems. \*The Round Three data is included with each question.

- 46. Statistics (Round Three Data: Mean=4.23 , Max=6, Min=1, St. Dev.=1.5892, IQR=3-5)
- 47. Calculus- Integration (Round Three Data: Mean=3.77 , Max=6, Min=1, St. Dev.=1.7394 , IQR=2-5)
- 48. Calculus- Differentiation (Round Three Data: Mean=3.77 , Max=6, Min=1, St. Dev.=1.7394, IQR=2-5)
- 49. Calculus- Differential Equations (Round Three Data: Mean=3.08 , Max=5, Min=1, St. Dev.=1.3205, IQR=2-4)
- 50. Measurement theory (Round Three Data: Mean=3.46 , Max=5, Min=1 St. Dev.=1.4500, IQR=2-4)
- 57. Modeling/simulation/numerical analysis software (Round Three Data: Mean=3.92 , Max=6, Min=1, St. Dev.=1.5525, IQR=3-5)
- 58a. Algebraic equations for determining gear ratios (Round Three Data: Mean= 2.75, Max=6, Min=1, St. Dev.= 1.4222, IQR= 1.75-3)
- 58b. Conservation of momentum (Round Three Data: Mean= 4.25, Max=6, Min=1, St. Dev.=1.2154, IQR=(4-5)
- 58c. Projectile motion (Round Three Data: Mean= 3.45, Max=6, Min=1, St. Dev.= 1.4397, IQR= 3-4)
- 58d. Structural equilibrium (Round Three Data: Mean= 4.33, Max=6, Min=3, St. Dev.= 0.9847, IQR= 4-5)
- 58e. Basic stresses (Round Three Data: Mean= 4.25, Max=6, Min=2, St. Dev.= 1.1254, IQR= 3.75-5)
- 58f. Using geometry and trigonometry to change the scale of a component (New item, no round three data)
- 58g. Formulas capable of expressing the performance of a system (New item, no round three data)

The next section consists of responses to Question 3: What specific science principles related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum designed to require secondary (high school) students to use various scientific principles to understand, manage, and solve technological problems. \*The Round Three data is included with each question.

- 60. Effects of chemical formulation on manufacturing (Round Three Data: Mean=2.75 , Max=4, Min=1, St. Dev.=0.7538, IQR=2.75-3)
- 61. Biological Evolution (Round Three Data: Mean=3.17 , Max=6, Min=1, St. Dev.=1.5859 , IQR=2.5-4) Comments from Round Three: For Q61, I put “1” since biological evolution has some scientific evidence to support it at the micro-evolution level but no evidence to support it at the macro-level. The concept of micro-evolution would be somewhat valuable to learn, but I don’t feel like the general concept of evolution would be valuable

- 62. Conservation of mass, energy, and momentum (Round Three Data: Mean= 4.92, Max=6, Min=2, St. Dev.= 1.2401, IQR= 4-6)
- 69. Control theory (Round Three Data: Mean= 2.83, Max=5, Min=1, St. Dev.= 1.3371, IQR= 2.5-3) Round Three Comments: Control theory is applicable to all engineering domains and is critical for understanding the behavior of all engineering systems.
- 74. Strength of materials (Round Three Data: Mean=4.25 , Max=6, Min=2, St. Dev.=1.1382, IQR=3.75-5)
- 75. Thermodynamics (Round Three Data: Mean=3.25 , Max=5, Min=2, St. Dev.=0.8660, IQR=3-4)
- 76. Decision analysis (Round Three Data: Mean=3.33 , Max=5, Min=1, St. Dev.=1.1547, IQR=3-4) Round Three Comments: Decision analysis is applicable to design practice in all engineering domains, and facilitates the application of well-considered design processes.
- 78. Learning theories (Round Three Data: Mean=3.58 , Max=6, Min=1, St. Dev.=1.6214 , IQR=3-4.5) Round Three Comments: Design is a learning-intensive activity. One cannot master designing without understanding his/her learning processes
- 79a. Project management (Round Three Data: Mean= 4.17, Max=6, Min=2, St. Dev.= 1.2673, IQR= 3-5)
- 79b. Thermal expansion/contraction (Round Three Data: Mean= 3.92, Max=5, Min=2, St. Dev.= 0.7930, IQR=4)
- 79c. Question asking -inquiry (New item, no round three data)
- 79d. Leadership principles (New item, no round three data)
- 79e. Principles related to environmental consciousness (New item, no round three data)

The last section consists of responses to Question 4: What specific skills, techniques, and engineering tools related to engineering design should secondary students use to understand, manage and solve technological problems? For each item below, please indicate your level of agreement with the following statement: This item is a critical and necessary component of an engineering design focused curriculum designed to require secondary (high school) students to use various skills, techniques, and engineering tools to understand, manage, and solve technological problems. \*The Round Three data is included with each question.

- 80. Computer aided design software (Round Three Data: Mean=4.33 , Max=6, Min=2, St. Dev.=1.2309, IQR=3.75-5)
- 81. Computer searching (Round Three Data: Mean=4.92 , Max=6, Min=4, St. Dev.=.7930, IQR=4-5.25)
- 89. Analysis-based design (Round Three Data: Mean=4.25 , Max=6, Min=1, St. Dev.=1.4222, IQR=4-5.25)
- 91. Failure mode and effects analysis (Round Three Data: Mean=3.00 , Max=5, Min=1, St. Dev.=1.2060, IQR=2.75-4)
- 93a. Reverse engineering (Round Three Data: Mean= 4.17, Max=6, Min=1, St. Dev.= 1.4668, IQR= 4-5)
- 93b. Finishing job to the last detail (Round Three Data: Mean= 3.92, Max=6, Min=1, St. Dev.= 1.4434, IQR=3-5)

- 93c. Recognizing team roles and personality types (Round Three Data: Mean= 4.58, Max=6, Min=4, St. Dev.= 0.7930, IQR=4-5)
- 93d. Engineering intuition (New item, no round three data)  
As planned, this final survey concludes the data collection portion of the Engineering Design in Technology Education study! I am most appreciative of your time and support - this study simply could not have been completed without your kindness. Thank you very much, Cameron Smith

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