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FEATURES OF ENGINEERING DESIGN IN TECHNOLOGY EDUCATION

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Critical Features of Engineering Design in Technology Education

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Abstract

The purpose of this study was to find critical features of engineering design that can be incorporated within technology education learning activities, and develop a rubric for assessing these features. Data were collected through semi-structured interviews with three professors actively involved in engineering education. Supporting documents such as engineering design course outlines and rubrics were also examined. Using a phenomenological approach, this study identified the concept of engineering design, key features of the engineering design process, and critical elements that should be assessed in an engineering design activity in the context of technology education. A key product of the study was development of a rubric to be used in evaluating integration of engineering design as a focus for technology education.

Introduction

The field of technology education stands at a critical juncture in its history. In a presidential address for the Council on Technology Teacher Education, Rodney Custer (personal communication, April 8, 2005) stated that while some very positive initiatives have taken place in the field of technology education, a number of critical problems must be addressed if the profession is to survive and thrive. Experts in the field

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of technology education argue that the discipline is viewed as a non-essential instructional program. They contend that research is needed to determine whether integration with other subjects would improve student learning of technological concepts and processes (Lewis, 2004; Wicklein, 2003).

Proceedings from the first and second American Association for the Advancement of Science (AAAS) Technology Education research conferences, documented on the Project2061 Web Site, highlight several key areas in need for research in the field of technology education. Bennet (1999), Rowell (1999), and Cajas (2000) stated that there is a great deal of research to be done in design education, technology education, and education that involves the process of solving problems and designing. The *Standards for Technological Literacy: Content for the Study of Technology STL* (International Technology Education Association, 2001) identified the importance of design when developing technological literacy. Morford and Warner (2004) stated that if these standards are to serve as a guideline for development of technological literacy, the profession should place some emphasis on the role of design in the study of technology.

So what is design? Design refers to the process of devising something. It is a creative, iterative and often open-ended process of conceiving and developing components, systems, and processes. Friesen, Taylor, and Britton (2005) described design as the creative, open-ended and experiential components that characterize problem solving. Jain and Sobek (2003) and Dym, Agogino, Eris, Frey, and Leifer (2005) stated that the past several decades have seen increasing emphasis being placed on design as the focus for engineering curricula. This view places design as the central or distinguishing activity of engineering and makes it a vital part of an engineer's preparation. At the graduate level, engineering programs of study typically prepare students to design effective solutions to meet social needs using the tools of engineering design (Sheppard, 2003). In view of this observation, experts in the field of technology education have identified engineering as a professional field that is closely associated with the study of technology. Professionals in both fields prepare themselves to solve modern societal problems that have practical importance.

To this end, the National Center for Engineering and Technology Education (NCETE) has proposed that the field of technology education adopt an interpretation of design based on the engineering definition. The center has advocated infusing engineering design as a focus for technology education curriculum and supported research related to this goal (NCETE, 2005). Shifting the focal point of an educational discipline is no easy thing, however. Raizen (1999) postulated that lack of clarity about the knowledge, processes, and skills to be mastered by students is a limiting factor for those seeking to implement an engineering design emphasis in technology education. Lewis (1999) stated that the relationship of technology education to other subjects in the curriculum was a fruitful area of inquiry. Lewis (2004) further posited that, it was imperative to find if integration of engineering design concepts into technology education helped learning of technological concepts and processes. These concerns shaped the rationale for this study and helped to frame a guiding question that asked, "What does it look like when an engineering design focus is successfully implemented within technology education?"

Popham (2004) defined assessment as a broad descriptor of the kinds of educational measurement that teachers use. He further described assessment as a formal attempt to determine students' status with respect to educational variables of interest. Variables are what teachers are interested in assessing. For example, if teachers are interested in how confident students are regarding their own sketches, then students' sketches would be a variable of interest. Raizen (1999) argued that assessment procedures required the identification of tasks and development of scoring rubrics. Prus and Johnson (1994) proposed competency measures (i.e. performance appraisals) as a method that could be used to measure outcomes with a focus on skills evaluation. Such an appraisal would provide a systematic measurement, usually in the form of a rubric, for an acquired skill (as cited by Shuman, Besterfielf-Sacre & McGourty, 2005). Rubrics define the criteria for assessment, qualities that will be assessed, and identify the levels of performance that students might demonstrate for each quality.

A rubric could be used as a key element of an assessment plan for technology education with an engineering design focus. Educators have found that rubrics improve achievement by establishing precise learning outcomes before products are created. Rubrics therefore can serve a formative role in learning by guiding students toward expected learning outcomes and a summative role as they are used to evaluate results.

Based on needs identified in previous scholarly work, the question that guided this study was, "What key descriptors of the engineering design process can be successfully implemented within technology education?" Responding to this question required the researchers to identify: what engineering design was, key features of the engineering design process, and critical elements that should be assessed in an engineering design activity within the context of technology education.

Purpose

The purpose of this study was to develop a process for identifying critical features of engineering design within technology education learning activities. A key product of the study was the development of a rubric to be used in evaluating integration of engineering design as a focus for technology education.

This study was guided by the following research questions:

1. What is engineering design?
2. What features of the engineering design process can be identified within the context of technology education learning activities, where engineering design is the focus for curriculum?
3. What practical strategies can be used to evaluate the infusion of engineering design into technology education learning activities?

Method

A key element of this study was to identify expert perspectives on critical features of engineering design that could be infused into technology education. A phenomenological research design was utilized as the researchers sought to find the essence of engineering design and how practicing engineers conducted it. In phenomenological research, the questions grow out of an intense interest in a particular problem or topic, the researcher’s excitement and curiosity drive the process (Moustakas, 1994). According to Van Manen (1990), phenomenology seeks the very nature of a phenomenon, for that which makes something what it is, and without which it could not be what it is. According to Hatch (2002) phenomenological researchers seek to reveal the essence of human experience by asking, "What is the nature of this phenomenon?" In the same vein, Van Manen (1990) stated that phenomenological researchers often view participants as co-constructors of the descriptions and interpretations of their studies. Therefore, phenomenology aims at gaining a deeper understanding of the nature or meaning of our everyday experiences and seeks to uncover the qualitative rather than the quantitative factors in behavior and experiences (Moustakas, 1994).

To gather such data, one must undertake long, in-depth interviews with people who have directly experienced the phenomenon of interest. Qualitative interviewing methodology enables inquiry and understanding of a societal or human condition, experience, or problem, based on construction of a complex picture that is formed mentally and analyzed inductively (Creswell, 1994). Bogdan and Biklen (2003) explained that qualitative research engages a limited number of participants in a deep systematic analysis of a phenomenon and is an appropriate research method when desired outcomes include description, interpretation, and a detailed understanding of the phenomenon. Pidgeon and Henwood (2004) argued that theory cannot simply emerge from data, because interpretation and analysis are always conducted within some pre-existing conceptual framework. Therefore, the epistemology for this research was constructionism. The focus of the proposed research was the construction of meaning from the perspectives of engineers with regard to features of an engineering design process. Constructionism is the view that all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context. Meaning is not discovered, but rather constructed (Crotty, 1998). In this study, three individual cases were jointly studied in order to inquire into the phenomenon of interest. A collective case study formed the methodology for this study. According to Stake (2000), a collective case study is an instrumental case study extended to several cases. An instrumental case study is the examination of a particular case to provide insight into an issue.

Participant Selection

Three professors actively involved in engineering education were purposively selected. Greg (pseudonym) and Keith (pseudonym) were both full-time assistant professors at doctoral-granting research universities. Greg taught undergraduate courses in engineering design, spatial data analysis, and graduate courses in open systems modeling and analysis, while Keith's areas of expertise centered on studying the mechanical engineering design process in order to develop enabling tools for designers. The third professor, Charles (pseudonym), was a full time associate professor with a scholarly focus on technology education and infusion of engineering design into the K-12 curriculum. He taught at a regional university. The selected participants were conversant about both technology education and engineering design.

Data Collection

Data collection methods consisted of two face-to-face and one telephone interview with each participant. The interview sessions lasted 40-50 minutes each and were audio taped and transcribed verbatim. In addition, a 75 minute lecture about design for manufacturing by one of the participants also contributed data used in this study. A semi-structured interview format was used in collecting data. Participants were asked about definitions of engineering design, how engineering design was different from technology education design activities, aspects of engineering design that could be infused into technology education, practical strategies used to evaluate an engineering design project, and perceived outcomes of infusing engineering design processes into technology education. Data was analyzed using phenomenological strategies as explained by Hycner (1985) and Moustakas (1994).

Data Analysis

To begin analyzing data, the researchers bracketed participant responses and sought to become aware of prejudices, viewpoints, and assumptions regarding engineering design. This helped them investigate engineering design from a fresh and open viewpoint without prejudgement or imposing meaning too soon. First, the three interviews were analyzed separately using Moustakas (1994) and Hycner (1985) guidelines. Each transcript was read with an open mind so that data could be approached without preconceptions about engineering design and general feeling could be developed regarding each participant's experiences. Next, the researchers reflected on the purpose of the study and the guiding research questions as they marked phrases and words that revealed each participant's perceptions of engineering design. As they read the interview transcripts several times, they jotted these words, ideas, thoughts, and phrases in the margins of each transcript.

Proceeding to a third step, the researchers engaged in horizontalization as suggested by Moustakas (1994). This process helped them list all expressions relevant to participant experiences regarding engineering design. These expressions were keyed into a word processor to generate a document that captured the essence of engineering design. Next, the researchers embarked on reducing repetitive meaning units to eliminate redundancy. Hycner (1985) pointed out that it was important to note the actual number of times a unit of relevant meaning was listed since that might indicate some significance as to how important that particular experience was to the participants. Having this in mind, the researchers took note of units to be eliminated, and those that would be retained. The researchers then clustered units of relevant meaning into themes, constructed new theme labels, and classified units under these new themes. Table 1 provides the themes identified during this stage of analysis along with category and subcategory labels and descriptions.

Discussion and Findings

This study sought to find out the critical features of engineering design in technology education and to develop a rubric for use in evaluating integration of engineering design as a focus for technology education. Quotes from participants are used throughout this section to emphasize core themes. Four core themes (process of engineering design, societal benefit, attributes of engineering design, and assessment) were identified from the reduced meanings of participant verbatim transcripts.

Core Theme: Process of Engineering Design. Charles stated that engineering design was an iterative developmental process that was broad in scope, a complex activity that was the heart of engineering, and was comprised of a problem, product, and process. He further stated that engineering design was a unique process. The English Oxford Dictionary defines *unique* as "one of a kind." According to Charles, the design process in engineering is a distinct activity that is clearly expressed, and it entails a systematic way of developing conceived solutions through the following steps: defining a problem, identifying a problem, conceptualizing possible solutions while incorporating stakeholder needs, conceiving a solution, developing predictive prototypes, and production.

Keith (pseudonym) shared the same sentiments but expressed himself using analogies to define design:

> Engineering design is what makes engineering, versus what makes engineering science. design essentially is a process, so we have a process that people follow to generate new ideas... ... you start putting in the details, see you have the skeleton and now you are putting the meat...

Design can be described in several ways; therefore, coming up with an absolute design definition is a difficult task. The definitions of the participants in this study revealed that the underlying aspects of any design work entail a process of steps which are developmental, structured, and iterative. To conceptualize possible solutions to design problems, engineers work in teams and have many design tools available to them to design products that meet societal needs. Figure 1 depicts a graphical representation of this process. In each of these steps one needs to stop to reflect on the whole process and then go back to the very beginning. It is not a linear process; rather the participants in this study explained that the engineering design process was broken into distinct structured steps or activities.

Table 1.
Themes Generated by Researchers

Categories	Sub Categories	Descriptions
Process	Defining a problem	Describing the nature of the question be solved.
	Identifying the problem	Establishing the specificity of the question to be solved.
	Conceptualizing possible Solutions—stakeholder needs	Generation of different solutions for questions to be solved, taking into consideration stakeholder and society needs.
	Conceiving a solution	Develop a possible solution for the question to be solved.
	Developing prototypes or predictive models	Construction of working models of conceived solution; should have a predictive element.
	Production	The act of creating the conceived solution, modeling the prototype that was most predictive.
	Systematic structure	This implies that an engineered design process should follow some form of step to step procedure.
	Iterative	This implies that the whole process is cyclic.
Societal	Improve Quality	This implies that an engineered solution should benefit and improve the quality of societal life; engineers should design with a purpose fulfilling a societal need.
	Safety need	The engineered solution should be able to meet societal safety needs.
	Concern	This implies that the predictable engineered solution should meet stakeholders concerns, societal concerns, constraints, etc.

(Table 1 continues)

Table 1. *(continued)*

Categories	Sub Categories	Descriptions
	Meeting needs	Does the solution meet the need for which it is being designed?
Attributes of Engineered Solution	Predictive element	Predictive implies that the engineered solution has some characteristics that help one to be able to foretell its behaviors or actions. An engineered solution is predictable because it is based on applications of math and science.
	Quantitative analytical aspect	This entails the mathematical rigor, the equations that will describe the function of the mechanism of an engineering designed solution. For example, if you take a designed object and drop it, there is a mathematical equation that will tell you when it will hit the ground.
	Qualitative aspect	This entails the descriptive aspects of an engineered solution and includes aesthetics. Most technology education products contain this aspect but miss the quantitative elements.
	Functional decomposition/ Analytical	This implies breaking the designed product into its component pieces and the ability to describe the function of each piece of the whole design.

(Table 1 continues)

Table 1. *(continued)*

Categories	Sub Categories	Descriptions
	Constraints	These are restrictions that are placed on an engineered solution by stakeholders or society; e.g. working within some specified budget or measurements adhering to specified state regulations.
	Optimizing	This is when you test to make the engineered product as effective or efficient as possible; this helps to reduce waste of time and resources.
	Logical	Implies that an engineered solution has followed some structured, systematic design process.
Assessment	Documentation	This is a collection of notes or records describing the steps that were undertaken to construct a product.
	Engineering design notebook	A notebook that contains all documentation of an engineered solution.
	Detailed graphical drawing	A detailed graphical output of solution.
	Constraints imposed	This implies the limitations that were imposed on the design of a solution.
	Fabrication and prototyping	This involves models or simulations constructed to showcase a final project.

Core theme: Societal Benefit. Participants in this study claimed that engineering designed solutions should be feasible and economical for society. Engineers should design with a purpose, and that purpose should be to fulfill a societal need. The engineered solution should adhere to safety concerns, be based on well defined constraints, and be sensitive to human needs. Keith stated that, “when you talk about designing anything, you have to design it with a purpose. For example, how does design relate to writing, well writing with a purpose would be to write a vacation guide or something to convey certain information?”

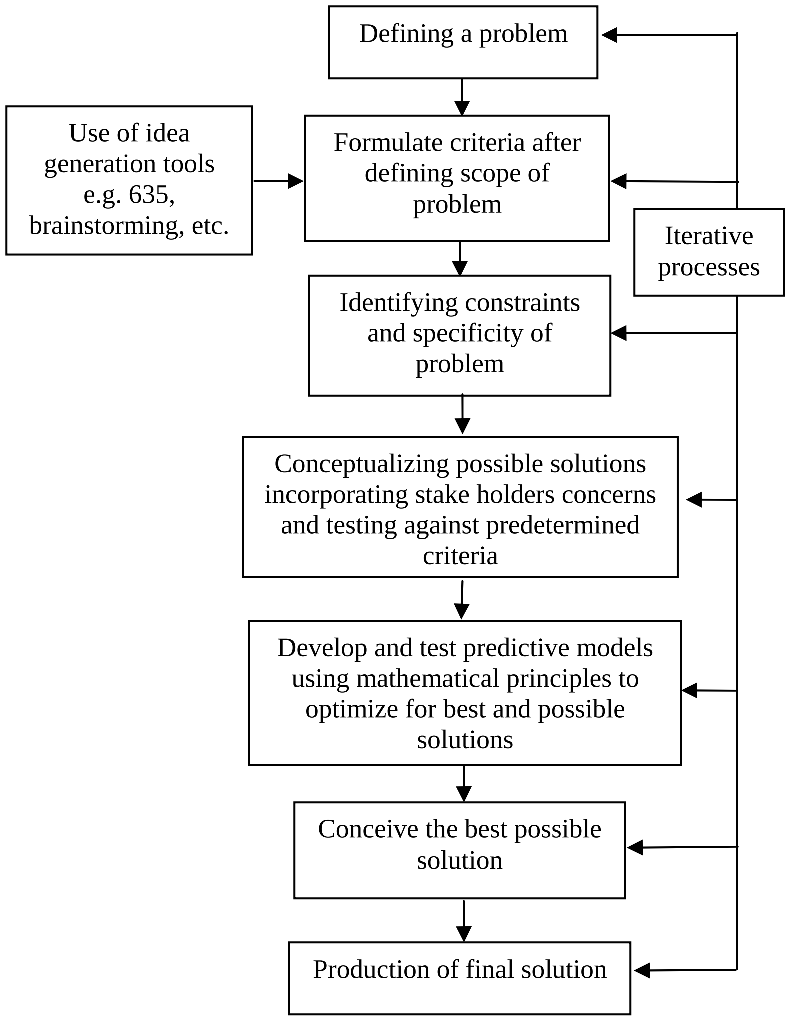

Figure 1. *Participant Perspective of the Engineering Design Cycle*

In the same vein, Greg stated that as much as math and science are required in engineering design, creativity was a desired feature also. It was noted that defining a problem, understanding a societal need, and being creative were all imperative steps in the engineering design process. This is what Greg said about designing to meet societal needs:

> what we are trying to focus them on is meeting a societal need, that is that the problem is open-ended.... yeah the math and science are necessary, but defining a problem and understanding societal needs is the most important part or you are not meeting needs. If you are not understanding needs then you can't meet needs, so we are trying to... really in engineering education you really want engineering students to be creative and sensitive to societal needs.

The solution should be engineered and designed to meet and improve the quality of life in a society.

Core theme: Attributes of Engineered Solution. Participants described critical features of engineering design to be characterized by engineered solutions. Attributes of an engineered solution varied according to participants' descriptions of these features. In this particular study, engineered products were portrayed to encompass the following characteristics: a predictive element, a quantitative aspect, a qualitative aspect, a functional decomposition element, optimization and analysis, and a life cycle phase. Each of these is further described below:

1. A predictive element. This implied that a user of these products would be able to foretell their behavioral actions whenever prescribed directions were implemented. In relation to this aspect, Greg said:

   > The engineered solution should be predictable. The technology education solution probably won't be; that is you couldn't predict the outcome of that solution. In this case the concern would be that you are building something to interact with human beings who have very, very sensitive needs in their lives.

   This is a very important characteristic because it also aligns with safety concerns and takes into account ethical considerations of any product that is being produced to interact with human beings.

2. A quantitative aspect. This entails the mathematical rigor that describes the function of the mechanism of the engineered solution. For example, if you take an engineered solution and drop it, there is a mathematical equation that will inform you when this object will hit the ground. If you throw it, there is a mathematical equation that tells you how long it will be in the air, how high it will go, and how far it may go. According to Greg, this product has an equation embodied in its functionality to describe its mechanism.
3. A qualitative aspect; this includes the descriptive aspects of an engineered solution. This may be the aesthetics or the beauty of the product.
4. A functional decomposition. This is where an engineered product can be broken into its compound parts and one would be able to tell the function of each piece of the whole design, what each part does, and how it does what it does. Keith stated that:

   > Reverse engineering, is what I think would be ideal for technology education so you teach the abstract concept of the engineering design process with an actual thing that exists. So you can take a toaster and you take the toaster apart and you document the toaster function of each part.

   Greg stated, "that is you decompose your design into its parts to determine what each part does, and when you put it together you know what each of those parts will do in the design."
5. Constraints. An engineered solution is designed and constructed within some prescribed restrictions, limits, or confines outlined by stakeholders. Charles said, "The fact that engineers are responsible to customers, taxpayers, government regulations, and such and are in such a position they are obligated." To this end engineers will work within some specified budget while adhering to state and federal regulations.
6. Optimization and analysis. This is when you run tests to make the engineered product as effective and efficient as possible. Optimizing alternative solutions helps reduce wasted time, materials, and resources, while analysis helps an engineer know how a product will do what it supposed to do, how well it will do it, and why it will do it. According to Greg and Keith, the reason that one is able to analyze an engineered product lies in the math and science language that is being used. Greg

referred to this math and science language as the quantitative aspect. He stated it was, "...an important aspect because it helped engineers to calculate amounts of parts, carry out brainstorming sessions, and choose the most appropriate solution. This is designing effectively and it ensures minimum waste, expense, or unnecessary effort." Therefore, engineering design solutions are based on in-depth analytical procedures and calculations to meet a societal need. According to Petroski (2002), the ability to perform calculations will help predict the performance of a design before it's built and tested. The engineer will be able to modify or remodify designs until its meets specified constraints and stakeholders' needs. Calculations can reveal potential failures without placing society at risk. It is important for an engineer to understand how and why alternative designs fail or can fail.

7. Life cycle. According to Charles, engineered products have a life cycle or some type of life expectancy. Charles stated,

    > Let's say for example if he or she were designing an automobile then there would be some consideration of the life expectancy of the product, how it would influence the environment, how it would appeal to customers in a marketing sense, and how it would be scrapped after its life.

8. The product will also have accompanying instructions of how it would be recycled or discarded after its functional use so that it meets ethical and environmental standards.

Core Theme: Assessment. The last concept to emerge from the data was assessment. Assessment meant looking at the employment of design tools, and the overall process the students undertook to develop the product. Keith stated, "There are no right and wrong answers." According to Keith, students should be evaluated in terms of presentations, both oral and written, the process they undertook to develop the product, the final product they came up with, teamwork, and how well they worked together. The evaluation should be on a continual basis. He stated that the evaluation of design was subjective as the practice of design, "…because I can't give them an 81% and I can't pin down, I can say this is generally an A or this is generally a C, but I can't say that this is a 94 and this one is a 72. So the evaluation of design is as subjective as the practice of design..."

To evaluate a design project would generally depend on the specificity of the design brief and if the students followed the design process to develop the solution. On the other hand, Charles stated that:

> A design project can be evaluated in terms of the engineering design process steps. Ethical considerations of the design team should also be noted.... Did the engineering design team conduct an economic feasibility study? Did the team work as in interdisciplinary unit, developing criteria and a process for analyzing each solution?

Evaluation of design work is a difficult task. One key aspect to note, according to Charles, is whether the design team worked as an interdisciplinary unit, adhering to set ethical standards and following a structured process for developing a solution.

Documentation of the whole process that was undertaken to develop the engineered solution is an important activity with regard to assessment. This documentation should involve a collection of notes, mathematical equations, graphical drawing, records of constraints imposed, description of the steps that were carried out to construct the product, documented criteria that were developed to analyze and compare each solution generated, and how a decision was reached regarding the best solution. In addition, appropriate communication of viable solutions to stakeholders is also an important process of engineering design. Greg stated:

> We would look at first the documentation. It's probably as important as anything else. We would look through their engineering design notebook to see from beginning to end if that notebook tells a story of how they identified their problem, what their solutions were, what they conceived, how they developed that solution, and how it changed as they performed different calculations to optimize the solution.

Communication and documentation stood out as important strategies to evaluate engineered solutions. A notebook with work records, sketches, and different concepts the students developed in the course of producing the final solution was imperative in assessing finished work. Students who documented and tested their solutions, went back in the process, and then identified a problem should not be penalized when assessment takes place. According to the participants of this study the essence of engineering design work is to be able to optimize, troubleshoot, and redesign efficient and effective products that meet a human need. Generally when conducting assessment of an engineering design activity one should ask the following questions:

1. Did the students complete or perform each of the steps in the design process?
2. Did they document the process they undertook and any other relevant information?
3. Did the design team work as an interdisciplinary team?
4. Did the engineering design team analyze models?
5. Did the engineering design team conduct an economic feasibility study?
6. Did they try to optimize the design before implementing it?
7. Did they develop criteria and a process for analyzing each solution, comparing each?
8. What was the quality of the solution and how was it selected?

Rubric Development

This study proposed to develop a rubric to be used in evaluating integration of engineering design activities as a focus for technology education. To develop such a procedure, engineering design evaluation strategies revealed assessment of student achievement as an important part of engineering education. A rubric could aid students as they critically reflect on their work during engineering design activities. Participants in this study discussed various ways they assess student projects. Student's portfolios in the form of project documentation, assessment by a panel of engineering faculty for industry-based projects, and presentations were all mentioned as important elements used in assessing student performance.

Charles indicated that assessment procedures should be developed to measure three types of engineering outcomes: design knowledge, design process skills, and the design product. Therefore, establishing engineering design outcomes would require that assessment be based on students' basic knowledge of the process of engineering design, application of this knowledge to solve the problem at hand, and the ability to conduct analysis to evaluate the design solution. Developing a rubric to measure engineering design outcomes would require identification of suitable tasks for performance assessment. According to Popham (2005), performance assessment is an approach to measuring a student's status based on the way a specified task is completed. Therefore, instituting a system for assessing engineering design projects would require the construction of performance objectives. These objectives would describe the skills and knowledge that students should be able to perform with respect to (a) the design product and process, (b) teamwork as the design team functions as an interdisciplinary unit, and (c) communication.

In addition, the *Standards for Technological Literacy: Content for the Study of Technology* STL (ITEA, 2001) outline benchmarks that students should be able to perform in order to develop an understanding of the engineering design problem-solving process. Students should be encouraged to use rubrics to enhance their skills and performance outcomes. Providing this learning tool would help students to critically think and reflect as they solve technological problems.

Identifying rubric-scoring criteria. A criterion, according to the Oxford English dictionary, is a standard, rule, or test on which a judgment or decision can be based. Thus, criteria specify observable details about a desired state. According to participants of this study, performance criteria would assess whether students achieved desired skill and knowledge reflecting the performance objectives. According to Keith (pseudonym), design tasks are usually open-ended and call for a process where several solutions can be conceived. Assessment of design products is a subjective process, which is difficult to quantify for purposes of assigning analytical scores.

Various measurement scales that indicate the level of competency can be used to assess student performance. For this study the terms *needs improvement*, *good*, and *excellent* were used to denote scoring levels. Needs improvement was a level denoting that the level of expected performance was lacking, good was a level indicating that the level of performance was average, while excellent signified that the expected performance was better than average. In addition, descriptive words were used in each level to convey various degrees of performance that students were expected to achieve and attain in order to meet stated performance objectives. The rubric shown in Figure 2 is the tool that was developed as a part of this study. Designing a standard assessment rubric for design-based problems was an extremely difficult but worthwhile experience. Design is subjective but can be denoted by performance indicators that educators should seek to cultivate in their students.

Engineering Design Rubric

Directions:
This rubric was developed to facilitate evaluation of the engineered design process. It includes examination of design (process and product), communication (written and oral) and teamwork. Please rate your experience using indicated descriptors; Needs Improvement (1), Good (2) or Excellent (3) by circling a number on the rating scale.

Objectives	Needs Improvement	Good	Excellent	Rating Scale
Design Product	Product marginally meets design problem requirements (unclear function, too expensive or impractical to produce, not safe, does not meet constraints)	Good (average) product meets basic design problem requirements (functions okay, produced within cost limits, meets constraints, meets some criteria, safety okay)	High quality (above average) product that meets and exceeds design problem requirements (meets budget, constraints, criteria, clearly safe and functions well)	1 2 3
	Product displays poor (below average) workmanship	Product displays good (average) workmanship	Product is aesthetically appealing and displays high quality (above average) workmanship	1 2 3
	Product lacks evidence of originality and creativity; marginally addresses design problem	Product shows some evidence of creativity and inventiveness; addresses design problem	Product shows significant evidence of originality, creativity and inventiveness; effectively addresses design problem	1 2 3
Design Process	Little evidence that external research was conducted to identify and describe nature of design problem to be solved	Evidence that some research was conducted to identify and describe nature of problem to be solved	Supporting evidence (research notes, illustrations, etc.) of external research identifying and describe nature of problem to be solved; research clearly documented in design notebook	1 2 3
	Little evidence that students formulated design criteria and constraints prior to selecting alternative solutions	Evidence that students formulated design criteria and constraints prior to selecting alternative solutions	Evidence that students formulated design criteria and constraints prior to selecting alternative solutions; clearly documented how criteria and constraints were developed in design notebook	1 2 3
	Little evidence that idea generation strategies (e.g. brainstorming, teamwork, etc.) were used to generate alternative solutions to solve design problem	Evidence that idea generation strategies (e.g. brainstorming, teamwork, etc.) were used to generate alternative solutions to solve design problem	Evidence that idea generation strategies (e.g. brainstorming, teamwork, etc.) are clearly documented in design notebook and were used to generate alternative solutions to solve design problem	1 2 3

Figure 2. *Engineering Design Rubric.*

	Little evidence that mathematical models were used to optimize possible solutions, incorporating identified constraints, criteria, and stakeholder needs	Evidence that mathematical models were used to optimize and describe possible solutions, incorporating constraints, criteria, and stakeholder needs	Evidence that mathematical models were clearly documented in design notebook and used to optimize, describe, and predict outcomes for possible solutions, incorporating identified constraints, criteria, and stakeholder needs	1 2 3
	No evidence that a prototype model of the best conceived solution was constructed and analyzed	Evidence that a prototype model of best conceived solution was constructed and some analysis conducted	Evidence that a prototype model of best conceived solution was constructed and analyzed, procedures/materials used were clearly documented in design notebook	1 2 3
	No evidence that test procedures were conducted to illustrate workability of model or prototype, neither were they documented in design notebook	Evidence that some test procedures were conducted to illustrate that model or prototype functioned and met specified constraints and criteria	Supporting evidence that test procedures were conducted to illustrate that model or prototype worked and met specified constraints and criteria; limitations were clearly documented in design notebook	1 2 3
	No evidence of iteration taking place in the design process	Some evidence that iteration took place throughout the design process	Supporting evidence that iteration took place throughout design process and details are clearly documented in design notebook	1 2 3
Communication	Reports and presentations lacked clarity	Reports and presentations describing design processes were provided and legible	Reports and presentations describing design processes were detailed clearly and provided in design notebook	1 2 3
	Design notebook entries were incomplete and lacked some key information	Clear and concise design notebook entries that are complete and without error.	Clear and concise design notebook entries that illustrate complete, precise sketches, calculations and notes that correlate with product	1 2 3
Teamwork	Individuals were frequently absent and team did not work as a unit	Team worked as a unit and was well organized	Team worked as a functional inter-disciplinary unit and was well organized; completed assigned tasks on time or early	1 2 3
	No evidence of team planning; team did not finish project within specified time	There was some evidence that team planned effectively and worked within time constraints to complete project	Team planned effectively, allocated group resources, documented activities in design notebook, and completed project within time constraints	1 2 3

Figure 2. *Engineering Design Rubric.*

Implications

Practical implications for technology teachers and students. The findings of this study can assist teachers implementing and teaching technology education with a focus in engineering design instruction at the K-12 level. A major implication for practice would be critical thinking and reflection about the iterative process and the use of analysis and optimization in engineering design. These aspects should be considered as significant components of technology education instruction for both teachers and their students. For teachers, critical thinking and reflection provide opportunities for development, application, and continued practice of the standards for technological literacy.

Implementing a focus on engineering design will influence both what is overtly and covertly being reinforced and rewarded in technology education laboratories. Participants of this study stated that the engineering design process was systematic and iterative in nature. Engineers worked in teams and carried out numerous tests to analyze and optimize the functionality of their final designs. In the same vein, teachers should seek effective methods to help their students reflect and think about the engineering design process and the functionality of problem solutions. Developing these skills will help them to develop skills to resolve life challenges faced on a daily basis.

For students at the K-12 level, critical thinking and reflection are key tasks each student can use for preparing their career development path and future employment opportunities within a technological world. Critical thinking and reflection offer students opportunities to make meaning of previous experiences and to identify alternative solutions for problems they face. Developing a clear understanding of engineering design through learning activities guided by the rubric developed as a part of this study can provide enhanced technology education opportunities. This rubric is presented in Figure 2.

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