ENGINEERING PROBLEM FINDING IN HIGH SCHOOL STUDENTS

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Dedication

This dissertation is dedicated to my grandparents, especially my grandfather George J. Mader. George was an expert problem finder and solver whose creativity and thirst for knowledge were, and remain, an inspiration in my life. The many hours spent early in my life observing him find and solve problems around the farm as well as the many educational adventures we embarked on tighter including several inventor’s fairs and threshing bees sparked both an interest in engineering and education which continue to this day. His patience and understanding in teaching me the ways of successful, creative problem finding and solving will not soon be forgotten. Though his lifelong thirst for learning as well as his mentoring, I have the opportunity to acquire some of these skills myself and to share them with others. I dedicate this dissertation to him and all of my grandparents who saw the value of education as a sign of my appreciation.

Abstract

The purpose of this study was to explore the engineering problem finding ability of high school students at three high schools in Minnesota. Students at each of the three schools had differing backgrounds including pre-engineering coursework, traditional technology education coursework and advanced science coursework. Students were asked to find problems in two different engineering scenarios which were presented to them on a paper and pencil instrument. Responses were scored by a panel of judges based on measures of creativity (flexibility, fluency, originality and elaborateness) and analyzed based on demographic data including gender, prior coursework and school. In addition student responses were categorized and evaluated qualitatively based on school and gender of respondent. Quantitative results indicate that the most consistent predictor of creativity in engineering problem finding scenarios was the number of advanced science classes. Specific measures of creativity included other significant predictors but advanced science coursework was the most consistent across all measures and scenarios. The qualitative results showed striking differences in the responses from students at different schools. Students from schools with a pre-engineering and advanced science emphasis found similar categories of problems and had a similar view of the purview of engineers while students with a technology education background focused on a rather different set of problems and had a much narrower view of engineering. Results show clear differences in the types of problems found by students at these three high schools as well as their understanding of the scope of engineering problems. Educators need to become more aware of the importance of problem finding in engineering and better encourage the development of problem finding skills among

their students. Specifically, technology education teachers may need supplemental professional development related to the scope of engineering and engineering problem finding as well as how these concepts might be infused into their curriculum and encouraged among their students.

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Chapter I

The Problem

Our lives and world seem to be teeming with problems. From how to save on gasoline to how to keep food from spoiling; and from how to maintain our ability to feed a growing population to how to protect endangered species we live in a world which seems defined by problems. For all of recorded history we as a society have relied on science and technology to help address problems such as these. From the earliest methods for farming to the invention of the wheel, sail and ship to the more recent advances brought about by electronics, computers and the Internet we see the importance of technology as a method for addressing a growing number of problems. Still, all of these advances in science and technology would remain purely intellectual curiosities were it not for people who can see a practical value to them and who have an ability to apply them to solving real problems.

As with most useful and productive services, over time a profession of people who use science and technology to solve real world problems has emerged. Many of those involved in this type of problem solving are identified either by themselves or others as engineers. The U.S. Department of Labor describes an engineer as someone who applies the principles of science and mathematics to economically solve technical problems (U.S. Department of Labor, 2007). Thus, when we talk about solving real world problems using technology and scientific discoveries in a systematic way we are really talking about engineering problem solving. It naturally follows, then, that engineers who are most familiar and most successful with problem solving and the skills it requires will turn out the highest quality solutions to the problems they examine.

As we do not live in an ideal world it is not enough though for engineers to design the best possible solution to a problem. Even in the definition provided by the Department of Labor we can see the influence of commercialization and economics. The solutions devised by engineers must not only be technically and scientifically feasible but must also be economically feasible. This wrinkle in engineering problem solving, which requires that a solution be economical, can add quite a bit of complexity to the problem solving process and necessitates that the best and most desirable engineers have superior problem solving skills.

Although the success of engineers is largely determined by their ability to solve these complex and ill-structured “real world” problems engineering schools often do a poor job of teaching students how to deal with these types of problems (Jonassen, Strobel, & Lee, 2006). The solving of problems with unclear goals and unlisted constraints is not something that students are able to learn through the structured problem solving they are most commonly introduced to in engineering classes (Jonassen et al., 2006). The problems discussed in school are typically designed to have a correct or at least apparently optimal solution to which the student’s solution can be compared. In the real world problems often have more than one appropriate solution and can require the balance of conflicting goals and other complex issues. More recent research has suggested that even the word or story problems that engineering students might be exposed to do not appear to provide adequate transfer to the solving of complex, ill-structured problems (Jonassen et al., 2006).

It is not just engineers though, who benefit from the practical application of science and technology to solve problems. As our daily lives have evolved and become more complex we have exposed ourselves to an increasing number of technological problems. For example, the majority of Americans living today take for granted the ability to control the climate in their homes through heating and cooling systems. The function of a building has evolved from a simple shelter from the elements to something expected to keep us comfortable year round but the increasing cost of energy is slowly causing us to re-think our living habits. Thus, the homeowner must now balance the desire for a comfortable home with the reality of the costs for maintaining such a home. These seemingly contradictory goals might be achievable or the situation improved though the application of scientific and technological principles in a problem solving process and the better that process the more satisfactory the end result.

Problems

It may not seem necessary to define what is meant by a problem. After all, we frequently use the term and nearly everyone has experienced a problem of some kind but when embarking upon a study of problems it soon becomes evident that “problem” is not a universal term and can have multiple meanings which must be differentiated.

Psychologist Karl Duncker (1945) begins his work on problem solving by describing problems as what occurs when someone has a goal but does not yet know how to meet that goal. This description of a problem as something which blocks the move from an existing state to a desired state is echoed by Simon & Newell (1972). Along these lines it is possible to describe what blocks this transition as a difficulty. The *Oxford English Dictionary* describes the most common uses of problem to be “a difficult or demanding situation; a matter or situation regarded as unwelcome, harmful or wrong and needing to be overcome; a difficulty" (2008) a description which clearly fits those provided by Duncker and Simon & Newell.

It is not merely enough though to describe a problem as a difficulty. Those problems faced by engineers and designers, while they may be difficult, are more than a difficulty. *Merriam-Webster's Dictionary* defines a problem as "a question raised for inquiry, consideration, or solution" (2008) which is a more appropriate definition in this case. Getzels (1982) suggests that in these cases instead of being a difficulty the development of the problem is itself the primary goal and what remains then, is execution. Furthermore, it becomes possible to classify problems based on whether the problem exists or is created, whether the problem is suggested by the solver or another and whether a known solution exists or must be devised. This method for classification of problems led Getzels (1964; 1982) to describe ten common types of problems:

1. The problem is given (is known) and there is a standard method for solving it, known to the problem solver (student, experimental subject) and to others (teacher, experimenter) and guaranteeing a solution in a finite number of steps.
2. The problem is given (is known) but no standard method for solving it is known to the problem-solver, although known to others.
3. The problem is given (is known) but no standard method for solving it is known to the problem-solver or others.
4. The problem itself exists but remains to be identified or discovered (become known) by the problem solver, although known to others.

5. The problem itself exists but remains to be identified or discovered (become known) by the problem solver and by others.
6. The problem itself exists but remains to be identified or discovered (as in 4 and 5) and there is a standard method for solving it, once the problem is discovered known to the problem solver and to the others (as in 1).
7. The problem itself exists but remains to be identified or discovered and no standard method for solving it is known to the problem solver, although known to others (as in 2).
8. The problem itself exists but remains to be identified or discovered, and no standard method for solving it is known to the problem solver or to the others (as in 3).
9. The problem does not yet exist but is invented or conceived, and a method for solving it is known or becomes known once the problem is formulated.
10. The problem does not yet exist but is invented or conceived, and a method for solving it is not known.

Jonassen (2000) takes a slightly different tack and suggests two critical attributes that something must have if it is to be a problem. First, there must be a situation with an unknown which is described as a discrepancy between a current state a goal state. This is similar to the definition used by Simon & Newell (1972). Secondly, there must be some social, cultural or intellectual value to finding or solving the unknown. The value could be either intrinsic or extrinsic but the key component is that someone feels that it is worth finding the unknown. Jonassen (2000; 2006) believes that there are three essential types of problems which form the basis for problem classification.

Puzzle problems are characterized by having a single correct solution which is arrived at using a specific procedure (Jonassen, 1997). Although multiple methods may accomplish the same end result only the single most efficient method is deemed to be the correct one. These are problems which have most commonly been associated with the study of cognitive problem solving, for example by Simon & Newell (1972). Such problems include the Tower of Hanoi, water jug problems and the nine dot problem familiar to cognitive process researchers. Jonassen (1997) suggests that while these are interesting from an initial research perspective they map poorly onto complex real-world problems and, as such, are not relevant to school learning or everyday practice.

Well-defined or well-structured problems are those which people are most familiar with and conditioned to solve, especially in the school setting. For example, when a math or science teacher writes problems for an exam or assigns “homework problems” they are most frequently well-defined problems. This is likely because well-defined problems have a definite solution process which requires the application of concepts, rules and principles from a given knowledge domain (Jonassen, 1997). In other words, well-structured problems are good for checking basic understanding and facts, something which is often the desired outcome of homework and exams. Jonassen (1997; 2000) describes well-structured problems as having a well-known initial state, a defined goal and known method for arriving at a solution. Although not explicitly identified as well-structured the first and second type of problems identified by Getzels (1964; 1982) are really examples of well-defined problems. These are given problems with standard methods for solving the problem and solutions can be compared to determine correctness. One common misconception about well-defined problems which Jonassen (1997) wishes to dispatch is the idea that skills learned in solving them will easily transfer to real world, ill-structured problems.

The third category of problem is the ill-structured or ill-defined problem. Unlike puzzle problems and well-structured problems this category of problem is frequently tied to a specific context and the information required to solve the problem is not all available in the problem statement (Jonassen, 1997; Jonassen, 2000). Many, if not most, of the problems encountered in daily life are of the ill-structured variety (Jonassen, 1997; Hill & Smith, 1998). For example, problems found or given to engineers and designers do not often contain all of the information required to solve the problem in the problem statement. There is also significant room for individual creativity in these types of problems as more than one correct solution may exist. Ill-structured problems will often require the application of multiple domains of knowledge and judgment calls which must be made by the problem solver (Jonassen, 1997). The problem types Getzels (1964; 1982) identifies as three through ten could be described as ill-structured problems in that multiple solutions might exist and the problem and/or the method for solving it is not fully understood.

For the purposes of this study the problems of interest are ill-defined questions raised for inquiry, consideration or solution. This is undoubtedly the most frequently encountered type of problem in the real world and that which is faced by designers and engineers on a daily basis. Although designers and engineers are often asked to “fix a problem” or are given what initially appear to be problems, they are often more accurately described as dilemmas, issues or scenarios. There is usually no immediately apparent path to solution and devising a solution will require the application of critical thinking skills and creativity. The dilemma or issue must also be somehow turned into a problem which can be solved.

Problem posing

The study of problem solving and the desire to utilize it in schools and workplaces is not a new idea. Early twentieth century educational researcher John Dewey (1910) proposed a five-step problem solving process which included: (1) felt difficulty, (2) problem clarification, (3) identification of possible solutions, (4) testing of solutions, and (5) verification of results. The four step heuristic model for problem solving proposed by mathematics researcher George Polya (1957) is similar to that of Dewey as it includes (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back, all of which can be seen in Dewey's five steps. One problem with models such as these are that they make the complex task of problem solving appear to be deceptively simple and can hide some of the processes which result in the most desirable solution. In his seminal study of problem solving psychologist Karl Duncker (1945) suggests that the process of finding a solution is more accurately seen as the continual reformulation of the problem. Over time this problem reformulation leads to the discovery of "essential" properties of the solution which, given knowledge of the domain, will in turn dictate an appropriate solution to the problem.

It may initially seem like a radical suggestion that the formulation of the problem is more essential than the solution but Duncker is not alone in this belief.

Scientists Albert Einstein and Leopold Infeld noted the importance of problem formulation in their discussion of the evolution of physics:

> The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science. (Einstein & Infeld, 1961, p. 92)

Einstein illustrates the importance of problem formulation by discussing the problem of determining whether light travels instantaneously or whether it occupies time, as sound does, a question posed by Galileo. Although the crude instruments of Galileo's time prohibited him from answering this question once he had formulated the question he was able to discern an experimental procedure which could be used, leaving the work to be done a matter of technical and experimental skill (Einstein & Infeld, 1961). Clearly, the experiment itself is not the most difficult part of this problem. Instead, the formulation of the problem is the true challenge and if we are to be good at the solving of problems we must be good at the finding of problems.

It is sometimes the case that when the topic of problem finding comes up it is asked "why do we need to seek out more problems when our world is already full of them?" While it is certainly the case that our world has many issues, dilemmas and quagmires but for these there is no immediately apparent path to solution (Getzels, 1979), they are not solvable in their current form. Returning to our earlier discussion of problems this can additionally complicate the categorization of problems as the initial dilemma may be presented to the problem solver but the problem to be solved remains to be found.

Take, for example, early prairie farmers who were able to harvest an abundance of grain on their remote but fertile ground. Someone may consider the problem to be that we did not have enough roads to transport grain to markets and ponder how to get roads built in these remote areas, but taking this view the problem domain has already been narrowed to building roads. As it turns out roads are not the only way to transport grain and may not be the most efficient for a specific situation. If a river is nearby or a number of farmers deposit grain in an elevator near them to which a railroad could be built these may be better solutions. Solving the problem for these farmers is aided by the finding or formulation of an underlying problem, the transportation of grain from farm to market, and the posing of questions such as the feasibility of centrally collecting grain prior to shipment or the proximity of a navigable river which may provide a better solution.

If then, the ability to solve complex and ill-structured problems is a critical skill and the formulation of problems or problem posing a critical and early step in the process of solving these types of problems should we not focus attention upon problem finding as a desired outcome of technology and engineering education? Unfortunately, problem finding has been largely neglected by researchers both as a whole (Getzels, 1979) and in the field of technology education (Lewis, Petrina, & Hill, 1998). It is the goal of this study to identify the state of problem finding in the high school classroom as it relates to the solving of technological problems and to compare the problem finding abilities of students from a wide variety of backgrounds.

Problem solving

Once a problem has been found the business of devising a solution to the problem can begin. The most basic description of problem solving comes from the seminal work of Newell & Simon (1972) which describes problem solving as the transition from an initial situation to a goal state by a narrowing of the problem space. The initial state, sometimes referred to as the problem state, encompasses the understanding of the situation as it exists. Take for example the dilemma of energy efficiency given earlier. In this case the problem state could include the thickness of walls, amount of insulation, price of energy, type of heating and cooling system, area climate and many other such factors. The goal state is the desired result and embodies the solution to the problem. In our example of home energy efficiency this could be the replacement of the heating system, additional insulation, use of passive solar design or many other solutions all of which could reduce climate control costs while improving efficiency. The link between the problem state and the goal state is the search for solutions through the narrowing of the problem space. This narrowing occurs as the problem solver searches through all the information they have access to which seems relevant to the problem including things in their memory and any research they conduct. Eventually the problem solver narrows the problem space enough to determine the solution to the problem (Newell & Simon, 1972).

Even in the example of home energy efficiency we can begin to see deficiencies in Newell & Simon’s description of problem solving. The problem has more than one solution and the problem space cannot be systematically narrowed until a solitary solution becomes obvious. Complex and ill-defined problems such as those most commonly faced by engineers and designers cannot be solved in Newell & Simon's simple problem space model (Middleton, 2005).

Recognizing the deficiencies in the simple problem space model as well as the extensive use of design in Australian technology classrooms Middleton (2005) modified Newell & Simon's simple problem space model to account for the characteristics of design problems including the ill-structured nature and potential existence of multiple solutions. The revised model replaces the problem state with a "problem zone" which allows you to start with an ill-defined and complex problem about which little is known. The goal state is replaced by a "satisficing zone" indicating an understanding that more than one competing goal may exist and a balance may need to be struck as well as the understanding that multiple solutions may exist. Finally, the simple narrowing of the problem space by searching is replaced by a complex search and construction process where numerous procedures are used which may be constructed or emerge. Another critical aspect of the revised model is that it is not a linear one, there remains a back and forth between the problem zone and the search and construction space as well as between the satisficing zone and the search and construction space (Middleton, 2005). This back and forth allows the problem to be redefined and the solution reexamined as the problem solving continues.

A focus on design and engineering

Technology education in the United States, like industrial arts and manual training before it, has traditionally focused on domain knowledge and production skills rather than on intellectual processes. In 1983 the landmark government report *A Nation at Risk* was published. Among other indicators that the American system of public education was on a dangerous path it was reported that high school students were lacking in intellectual skills, such as problem solving, which should be expected of them (The National Commission on Excellence in Education, 1983). The concerns identified in *A Nation at Risk* were reiterated in 1991 with the publication of *What Work Requires of Schools: A SCANS Report for America 2000*. Again, intellectual skills and problem solving were identified as lacking as critical skills in American students (The Secretary's Commission on Achieving Necessary Skills, 1991). Taking note of this shift in the workplace, Johnson (1992) wrote in the *Journal of Technology Education* about the critical nature of intellectual skills and suggested that the field adopt a curriculum emphasizing intellectual skills such as problem solving through ill-structured, design oriented problems.

In 2000 the International Technology Education Association published the *Standards for Technological Literacy*, a set of content standards for the study of technology in schools. Out of the twenty standards four are entirely focused on the design process and several others make note of the importance of design (International Technology Education Association, 2000). Many cognitive scientists consider design to be a special case of problem solving (Newell & Simon, 1972) so the inclusion of design in standards such as these can be interpreted as an explicit inclusion of problem solving.

Although technology educators in the United States have been slow to fully integrate a design process in their curriculum other parts of the world have truly embraced design as a foundation for technology education. The British, too, were concerned about the gap between education and industry but their wake up call came with the release of the *Crowther Report* in 1959 (Gradwell, 1996), several decades before *A Nation at Risk* and the *SCANS* report were released in the United States.

Beginning in 1963 British researcher Gerd Sommerhoff opened the Technical Activities Centre at Sevenoakes School in Kent (Gradwell, 1996). This center was designed squarely to address the gap between education and the workplace, especially the field of engineering, through student designed projects requiring both creativity and problem solving skills (Gradwell, 1996). From the late 1960s through the 1970s the ideas promoted by Sommerhoff were propagated to other schools in Great Britain and design based problem solving slowly became a regular part of the curriculum (Gradwell, 1996). The late 1980s and early 1990s saw the introduction of a national curriculum in the United Kingdom aimed at ensuring that all students learn essential knowledge and skills. One of the subjects selected for inclusion in this curriculum was Design & Technology, a subject heavily influenced by the ideas of Sommerhoff almost thirty years earlier (Atkinson, 1990; Gradwell, 1996).

The advent and subsequent revisions of the national curriculum in the United Kingdom have firmly entrenched the idea of design and problem solving within their technology curriculum while schools in the United States continue to struggle with the idea, though some progress is being made. In recent years the field of technology education in the United States has been moving towards a more engineering and design focused curriculum. Articles by respected technology education researchers (Lewis, 2005a; Wicklein, 2006) as well as the inclusion of design standards in the ITEA *Standards for Technological Literacy* (2000) indicate the increasing interest in engineering and design as content and a framework for the study of technology. As engineering and design curriculum continue to propagate through American schools there will need to be continued research which aids us in understanding student problem solving both in how problem solving can be nurtured in students as well as appropriate methods for the assessment of problem solving.

The study presented here focuses on describing the state of engineering problem finding at three high schools in Minnesota. Each of the schools is unique in how students come to know and understand engineering. One school follows the Project Lead the Way engineering program, a second has traditional technology education courses and a third which has neither but prides itself in having extensive enriched and advanced science courses. The student bodies are also different with one school located in an exurb, the second in a rural town of moderate size and the third in a first ring suburb which prides itself in high achievement.

Students at these three high schools were asked to take part in this anonymous study of engineering problem finding by providing basic demographic information including gender and a list of high school engineering, technology and advanced science classes. The students were then presented with two engineering scenarios and asked to develop and describe problems which, if solved, would improve each situation. The first of the two scenarios revolved around increasing the energy efficiency of homes under development while the second asked about a town subject to flooding issues from a local river. A copy of the instrument used is located in Appendix A.

Problem Statement

Complex and ill-structured problems such as those commonly found within the design and engineering fields require that solvers have the ability to define and question the problem itself through a process of problem finding but the research on problem finding in technology and engineering education has not been extensive and we do not know whether high school engineering curricula support this critical skill in problem solving.

Guiding Research Questions

1. How do the problems identified by students at three Minnesota high schools compare on known measures of creativity?
2. Does gender make a difference in the types or creativity of problems posed by students from three Minnesota high schools?
3. Does coursework or curriculum make a difference in the types or creativity of problems posed by students from three Minnesota high schools?
4. What do the problems posed by students at three Minnesota high schools reveal about their understanding of the nature of engineering?

Chapter II

Review of the Literature

As has already been indicated in the first chapter there has been a recent turn towards engineering and design in the field of technology education. The publishing of the *Standards for Technological Literacy* (International Technology Education Association, 2000) with their emphasis on design makes it a foregone conclusion that design will continue to increase in importance within the American technology education curriculum as time goes on. Arguing that the field should go one step further and specify engineering design as the primary content for the study of technology are researchers such as Wicklein (2006) and Bensen & Bensen (1993). When combined with movement in the engineering field emphasizing the importance of technological literacy by groups such as the Institute of Electrical and Electronics Engineers (IEEE) though their pre-university education division and the desire of the National Academy of Engineering to make engineering more accessible to students from a variety of backgrounds (Pearson & Young, 2002) it seems that engineering design will become a part of technology education.

The types of design based problems which an engineering design curriculum suggests will be somewhat different in nature than the assignments which have been typical in the technology education and industrial arts classrooms of the past. For one thing some researchers have called for the integration of more math and science in engineering design (Cotton, 2002; Roman, 2001; Wicklein, 2006). Other researchers such as Lewis (2005a) have noted that students and teachers will need to have content knowledge of engineering design as well.

Engineering design and problem solving

Although there is not one unified engineering design method or process across all fields or schools of engineering there is some agreement on the basic stages of engineering design. Furthermore, if we consider design to be a specialized form of problem solving, as was indicated in chapter one, and we consider engineering design to be a subset of design we can begin to see the interaction between problem solving methods and engineering design methods. Take for example the five step problem solving method proposed by Dewey (1910):

1. Felt difficulty
2. Problem clarification
3. Identification of possible solutions
4. Testing of solutions
5. Verification of results

Compare this with the thirteen step engineering design process used in the engineering school at Dartmouth (Garmire, 2003):

1. Define the problem
2. Restate the problem
3. Develop constraints/criteria/specifications
4. Brainstorm ideas
5. Research alternatives
6. Analyze alternatives by trade-off matrix
7. Identify a potential solution
8. Research in detail the potential solution

9. Design a potential solution
10. Construct a prototype
11. Evaluate prototype
12. Reiterate if necessary
13. Simplify if possible

Although the Dartmouth engineering design process is significantly more verbose than Dewey's method of problem solving there are distinct similarities. Steps one to three in the Dartmouth process map quite well onto steps one and two of Dewey's, steps four through eight onto step three of Dewey's, steps nine and ten to step four of Dewey's and steps eleven and twelve onto step five of Dewey's. The thirteenth step of the Dartmouth model is not specifically addressed in Dewey's but this step is calling for the evaluation and reiteration of the process, something which is frequently discussed in relation to problem solving methods but which does not often receive its own step.

Of most interest to the purposes of this study is that both the problem solving method proposed by Dewey and the engineering design method used at Dartmouth specifically include steps where the problem is defined and clarified. The Dartmouth model goes so far as to suggest that the problem be restated, language which is not all that different than the reformulation of the problem suggested by Duncker (1945). This clarification, restatement or reformulation of the problem can be understood to mean the finding of the true problem as discussed in the first chapter. Thus, both the problem solving and engineering design processes will require problem finding or question posing abilities.

Collegiate engineering education researchers are also coming to understand the importance of problem finding in engineering. Atman, Yasuhara, Adams, Barker, Turns & Rhone (2008) point out the skills required of modern engineers:

> "Today's engineers must have mank skills to succeed in the increasingly complex world of engineering work. These skills include, among others, and ability to define problems as well as to solve them, a tolerance for ambiguity, design judgment, an understanding of uncertainty and an appreciation of the impact of designed solutions on the people and environment they interact with. Because engineering is situated in real contexts, an ability to consider broad impacts (encompassing technical, social, economic, political, cultural and environmental considerations) is a particularly important aspect of being a successful engineer." (p. 234)

If these skills, echoed in Hill & Smith (1998), are to be required of successful engineers they will need to be taught and assessed by engineering educators. Thus, a need arises to find ways to assess the success of teaching engineering students to think broadly. It is for this reason that Atman et al. (2008) turn to research on problem finding where designers explore the issues surrounding a design challenge and determine what the boundaries are for the problem they will ultimately solve.

Atman et al. (2008) used verbal protocol analysis to examine the factors college freshman and senior engineering students took into account when designing a flood retaining wall system for the Mississippi River. The so called 'Midwest Floods' problem was designed to be both something encountered in the real-world by engineers and a problem which is ill-structured. The verbal protocol of participants was coded based on the physical location of factors they would consider (wall, water, bank, and surroundings) as well as the frame of reference (technical, logistical, natural, and social) by two coders.

As a result of their study Atman et al. (2008) discovered that both freshmen and senior engineering students considered broad, contextual issues in the formulation of engineering problems. Further analysis suggested that there are differences between freshmen and seniors in problem scoping, both in terms of the quantity of factors considered and the breadth or variety of factors considered. Based on this and other analyses Atman et al. (2008) suggest that as engineers grow from novices to experts in problem scoping they begin to continually revisit problem scoping throughout the design process rather than concentrating most scoping behavior at the beginning of the process. It is further suggested that the Midwest floods problem could be useful in evaluating the success of design education efforts.

In 1984 researcher Jonathan Smilansky noted both the critical importance of problem formulation and question posing while also noting that little research had been done on the relationship between problem solving and problem finding and question posing. In an attempt to fill this void and connect the ideas of creativity and intelligence Smilansky set about designing a multi-part empirical study to assess what, if any, relationship existed between problem solving ability and problem finding or question posing ability.

One major hurdle for Smilansky’s (1984) study was that problem finding studies to that point had primarily utilized observation of a relatively small sample and did not have a scoring system conducive to large samples. This required Smilansky to develop both a paper instrument which could be administered in quantity and a scoring system to link problem solving ability with problem finding ability. Because the investigation was to look at this link Smilansky wanted to remove the influence of both content knowledge and prior experience. To achieve this end he settled on using a variation of the Raven Progressive Matrices test where he first asked students to solve a series of matrix problems and then to invent their own more difficult matrix problem.

Smilansky (1984) concluded that although only a very low correlation existed between problem solving scores and the ability to create new problems a relationship did exist. By noting that participants wither performed well or poorly on both tasks, or their problem solving ability exceeded their capacity for problem invention he determined that the creation of new problems is more difficult than solving existing ones. Smilansky further suggested that the ability to solve problems was a necessary but not sufficient condition for inventing new problems.

These results indicated to Smilansky (1984) that two different intellectual processes were taking place. He further suggested that creativity is centered on the ability to pose high level problems while intelligence is reserved for the ability to solve problems identified by others. In this way intelligence would be seen as the ability of an individual to apply knowledge and experience as a tool while creativity is seen as the more desirable and higher order ability to formulate the problem (Smilansky, 1984).

Problem finding in schools

Problem finding is not solely the domain of cognitive psychologists and others studying the problem solving process. Within the subjects of math and science problem finding and question posing have been identified as legitimate methods for teaching and learning. In the 1960s mathematics researchers Stephen Brown and Marion Walter taught a series of courses on problem posing at the Harvard Graduate School of Education (Brown & Walter, 1990). These courses were initially only designed as a small extension of the work on problem solving in math by George Polya but turned out to be the beginning of extensive interest in problem posing. In the subsequent decades Brown and Walter taught a number of seminars on problem posing at colleges around the country. In their 1983 and 1990 books *The Art of Problem Posing* Brown and Walter suggest that when teachers step away from the traditional format where they and the text are the authority and ask questions for students to answer and move towards encouraging students to ask questions there are profound effects on student learning. While they note that it has been good pedagogy to encourage students to ask questions for some time the types of questions that students typically ask are of the procedural nature and not deep or particularly insightful (Brown & Walter, 1990). The goal of their work is to encourage teachers to incorporate problem posing by students into the introduction of new material in a way which slows the students to build relationships between new and old concepts and cement understanding.

Brown and Walter are not alone in encouraging mathematics teachers to utilize problem posing in the classroom. The National Council of Teachers of Mathematics (NCTM) has also suggested problem posing for use in mathematics education (National Council of Teachers of Mathematics, 1989; National Council of Teachers of Mathematics, 1991). Many additional mathematics education researchers have noted the central importance of problem posing in mathematics education (English, 1998; Silver & Cai, 1996; Silver, Mamona-Downs, Leung, & Kenney, 1996). At the same time

English (1998) noted that despite this importance there has been limited research on the ability of children to create their own problems and on the success of curriculum targeted at improving their problem posing skills. Silver & Cai (1996) also suggest that much of the interest in mathematical problem posing has been at the elementary level and that practitioner interest has outpaced the research on problem posing specifically citing the assessment of problem posing as an area of need. Another potential concern for mathematics educators is that much of the research that has been conducted on problem posing refers to problem posing as the generation and reformulation of problems which allows for the solving of them as was suggested in the first chapter. In contrast much of the interest from mathematics educators is in the actual process of problem posing itself and the creation of problems based on experience and curiosity (see Brown & Walter, 1990), an area in which there is much less hard research (Silver et al., 1996).

Mathematics is not the only school subject with interest in problem posing. Despite the perceptions of students that science is about the study of scientific laws and facts there is a strong interest in the thinking and the ability to solve conceptual problems requiring intellectual skills (Dori & Herscovitz, 1999). Along these lines there is increased interest in alternative evaluation methods which would allow for the measurement of these skills in students. One method suggested by Dori & Herscovitz (1999) was the measurement of problem posing as an alternative method for evaluation in science. Shodell (1995) has also suggested that a primary function of science education should be the development of problem posing capability in students.

Echoing many other authors, Hoover & Feldhusen (1990) and Hoover (1994) suggest that the ability to formulate effective problems is a critical skill with an impact on subsequent student success. They argue specifically that while much of science education is focused on the testing of hypotheses a great area of need exists in teaching students to develop appropriate hypotheses, a process they suggest is the manifestation of problem finding in science. In an effort to explore this line of inquiry two similar studies were undertaken by the researchers.

Both Hoover & Feldhusen (1990) and Hoover (1994) utilized similar methods to explore hypothesis generation as problem finding among gifted ninth grade (Hoover & Feldhusen, 1990) and fifth grade (Hoover, 1994) students. In both cases relationships between cognitive variables such as scores on the Cognitive Abilities Test (CAT) and Differential Aptitude Test (DAT) and non-cognitive variables such as scores on the Intolerance of Ambiguity test, the Attitude Towards Problem Solving inventory, the Science Attitude Questionnaire and gender were examined. The 1994 study also added the dimension of verbal creativity though an administration of the verbal form of the Torrence Test of Creative Thinking. Both studies used a written form of Frederickson's Formulating Hypotheses Test, scored by a panel of judges, to assess the ability of participants to formulate hypotheses for several realistic scientific situations.

In both the 1990 and 1994 study the researchers found no practically significant relationship between the measured variables and performance on the formulating hypotheses test. They also found no relationship between gender and hypothesis formulation ability. It was noted in the 1994 study of fifth grade students that the ninth grade students studied in 1990 did quite a bit better and was further hypothesized that the quality and quantity of scientific problems students are able to formulate increases with age.

The results of the study by Dori & Herscovitz (1999) indicated that problem posing can both be used as an alternative evaluation method for case-based learning in the science classroom and the inclusion of a problem posing component to these cases can measurably improve student performance on measures of problem posing. Though not yet as extensive as the interest in mathematics there appears to be continued interest in the study of problem posing by science educators.

Although the use of problem posing itself as a teaching and learning tool by mathematics educators is interesting and does have some potential to add to the literature on problem posing it is not as relevant to engineering design as the use in science. Much like technology educators, science educators have seen the development of critical thinking and problem solving skills an essential part of their curriculum. It is in this effort to encourage scientific thinking and conceptual understanding that science educators have become interested in problem finding. The research by Dori & Herscovitz on problem posing as an alternative evaluation method might be of special interest to the engineering and technology education field. Similarly, the research by Hoover & Feldhusen (1990) and Hoover (1994) on hypothesis development, a task central to science and which they suggest is missing in science education, suggests that engineering problem finding may be a critical but missing link in engineering education and warrants closer examination.

Educational researchers Lee & Cho (2007) also looked at problem finding in science. Their interest in problem solving comes from the view that problem identification is the first step in good problem solving and leads to more effective, innovative, and creative solutions. It was the goal of their study to understand what variables might affect scientific problem finding in an effort to determine areas which could be targeted to improve student scientific problem finding ability.

To go about this exploration of scientific problem finding Lee & Cho (2007) measured several variables though a series of tests which they believed may have an effect on problem finding. The variables measured were intelligence, scientific knowledge, science process skills, divergent thinking, intrinsic and extrinsic motivation, personality traits and creative home environment. In addition, Lee & Cho (2007) felt that some of the discrepancies in prior problem finding research may be explained by how structured the situation presented to students was. In an effort to test this they administered two separate problem finding tests which they developed. One group of students received a moderately structured scenario while another received an ill-structured scenario. Student responses were scored by a trained panel of judges on measures of appropriateness, originality and elaborateness.

The results of the Lee & Cho (2007) study indicated that students were more likely to find appropriate, original and elaborate problems in the ill-structured scenario than in the moderately structured scenario. In addition, the effect of the measured variables changed based on how structured the presented scenario was. One of the interesting findings was that in the ill-structured situation scientific knowledge was a predictor of problem finding performance (Lee & Cho, 2007). Based on this finding Lee & Cho encouraged curriculum developers to consider scientific knowledge in curriculum designed to boost scientific problem finding performance. Conversely, ill-structured problem finding performance may be indicative of knowledge and useful for knowledge assessment.

One of the major issues teachers have with problem based learning and the type of team oriented design problems that are encouraged in engineering curriculum is the difficulty in assessing student performance. Design is so often a subjective assessment, something that can be difficult to justify to parents and students even when rubrics are used. Furthermore, the group process which is frequently used in these scenarios can leave a teacher with little information about the thinking which went into a design and which might be of use in determining a grade. The use of problem posing as an alternative evaluation method has the potential to give teachers some additional information about student thinking and the creative process which led them to a specific design, something which would be of certain interest for instructors who are frequently asking students how they arrived at a particular design.

Creativity

Until Guilford published his seminal work on creativity in 1950 psychologists and cognitive scientists had largely ignored it as a vein of research (Getzels & Csikszentmihalyi, 1976). Since that time there has been an explosion in creativity research which has frequently centered on problem solving (Weisberg, 1988). Despite this focus much of the research was conducted using the extremely well structured and defined puzzle type problems which are not conducive to an examination of creative problem solving (Jonassen, 2000). Furthermore, it is often the case that researchers looking at problem solving will largely neglect creativity in their study. For example the seminal study of human problem solving by Newell & Simon does not even include creativity in the index. Still, the interest in linking problem solving and creativity remains strong. Noted researcher on creativity and developer of the *Torrance Tests of Creative Thinking* E. Paul Torrance (1966) states that:

> "Creativity is a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficult; searching for solutions, making guesses or formulating hypotheses about deficiencies, testing and re-testing these hypotheses and possibly modifying and retesting them, and finally communicating the results."

This view of the creative process is not all that different from the problem solving and engineering design processes we have already discussed. In fact some examples of the creative process seem to be derived from the engineering design and problem solving processes. Take for example the creative process identified at General Electric (McPherson, 1964, p. 133):

1. Define the problem
    a. Establish the problem
    b. Investigate approaches
2. Search for methods
3. Evaluate all methods
4. Generalize the results
5. Select method
6. Make the preliminary design
7. Perform test and evaluation
8. Generalize the results

9. Find the best solution

Although this has been identified by McPherson as a creative process it looks very much like an engineering design process which makes sense given the tie to General Electric, a firm more known for engineering than for art. Aaron Blicblau and Joseph Steiner (1998), in an article about creativity and engineering, suggest that it is the process of solving problems itself which instills the need for creativity in engineering. Indeed, there is much literature which links creativity with problem solving. For example, Weisberg (1988) explains the solutions typically given to Duncker's (1945) candle problem as creative responses to a novel situation.

The conclusions of Weisberg tend to agree with the Perkins' (1990) discussion of what constitutes creativity. According to Perkins before we can understand creative thinking we must understand what people identify as creative thinking, usually related to an outcome. Also, it is not just traditional creative activities such as painting, writing, music and theater which can be creative outcomes. Perkins believes that creative outcomes can include "poems, paintings, scientific theories, business plans, jokes, flower arrangements, cakes, games, and conversations" (1990). By extension it would be possible to include the solutions to engineering design problems among these creative outcomes. As for what makes the outcomes the result of creative thinking, Perkins believes that it is ideas which are both novel and appropriate to the situation which are identified as creative ideas (1990).

There has been some debate within the psychological community about whether or what type of relationship exists between creativity and intelligence. In his seminal article *Creativity* Guilford (1950) notes that although laypeople may believe creativity is only within the grasp of gifted individuals he believes that it exists to some degree in everybody as we all partake in creative thinking from time to time. As evidence of this belief he notes that the term genius, originally used to describe the exceptionally creative, has been co-opted and is now used to describe those with exceptionally high IQs (Guilford, 1950). Furthermore, it is noted that Binet's IQ test has been validated for use primarily as a predictor of academic performance in reading and mathematics and as such has limited applicability in the creative domain (Guilford, 1950). Despite Guilford's insight into creativity and his belief that we must look beyond general intelligence when examining the domain of creativity he still believed that it was individuals with exceptional levels of fluency, flexibility and other extraordinary thought processes who did creative things (Guilford, 1950; Weisberg, 1988). This has been largely discounted by more recent research although the idea that there is something abnormally special about creative people continues to pervade society (Perkins, 1990; Weisberg, 1988).

One of the challenges in studying creativity is that of predicting and measuring creative performance, especially on a large scale. Much of the older research on predicting creativity used standard measures of divergent thinking such as the Uses, Instances, and Similarities tests by Wallach and Kogan (Okuda, Ruco & Berger, 1991). In an effort to improve upon these measures Okuda et al. (1991) and Chand & Runco (1993) began to examine the use of real world problem finding as a predictor of creative performance. These two studies utilized written problem finding and solving exercises, standard measures of divergent thinking and the Creative Activities Checklist. The key observation of both Okuda et al. (1991) and Chand & Runco (1993) was that real world problems and problem finding tasks can be significantly more predictive of extracurricular creative activities than traditional divergent thinking tests.

Although variables such as personality, values, intrinsic motivation and discovery orientation have been suggested as predictors of creativity these, by themselves, leave much variance to be accounted for (Csikszentmihalyi, 1994). It is in this frame of mind that Csikszentmihalyi came to believe that creativity is more than just an individual trait and that it is based in a social and cultural context. According to Csikszentmihalyi the difficulty in studying creativity comes from the difficulty of defining it. In other words, all measures of creativity come down to a judgment call at some point. There is an individual or panel of individuals who must determine if something is creative or not. Even under the best circumstances these evaluators are bound by the current values and norms as they determine creativity. It is even true that in some cases individuals who were not considered particularly creative by themselves of their contemporaries are later judged to be creative based on their contribution to overall development. Thus, Csikszentmihalyi concluded that “creativity is not an attribute of individuals but of social systems making judgments about individuals” (1994). Although this does not reduce the importance of creativity it does mean we need to consider more than the individual when we examine creativity, we must think about the environment.

Creativity in engineering design

While it is the case that many engineers are initially drawn to the profession by an interest in gaining the ability to solve real-world problems, problems which would require creative solutions, these are not the types of problems which they frequently encounter in the engineering schools (Blicblau & Steiner, 1998). In contrast, there is a concern among some engineering educators that the engineering science based curriculum which pervades most schools of engineering has the opposite effect, that of stifling creativity (Blicblau & Steiner, 1998). Noting that engineers must frequently work within the confines of legal requirements, cost requirements and material properties Blicblau & Steiner (1998) believe there remains a need to foster creativity in these students. One way they propose doing this is though the integration of capstone projects. It is their belief that these projects simulate realistic design scenarios and improve students' understanding, motivation and creativity (Blicblau & Steiner, 1998).

There is also a concern among the engineering profession that problem solving has become too analytical and procedural (Lumsdaine & Lumsdaine, 1994). The concern is that students in engineering schools are learning "engineering by formula" and are being taught with neat problems which will never be seen in the real world and which do not transfer well to the complex nature of real problems. This "plug-and-chug" method of engineering is not only what industries hiring engineers want to avoid, it is also a less efficient method of arriving at a solution (Lumsdaine & Lumsdaine, 1994). What Lumsdaine & Lumsdaine propose is that students be familiarized with working in real-world contextualized situations throughout their engineering school careers and that creativity in design is encouraged rather than discouraged.

This is not to say that engineering schools are all discouraging creativity or the creative design process. Quite the contrary, some engineering schools have made tremendous efforts to include creativity within their curriculum. Even going back to 1960s there were engineering educators concerned about incorporating creativity within their curriculum. In their discussion about the importance of creativity in engineering Mathews & Bailey (1965) discuss their course in creative problem solving for engineers. They note with concern the "one problem-one solution" belief among many engineering graduates of the day as well as the fact that virtually all leaps forward in engineering have been the result of someone being willing to depart from conventional thinking and take a risk with an original idea (Mathews & Bailey, 1965). Like Lumsdaine & Lumsdaine (1994) they believe that the industries which employ engineers are more interested in those engineers with creative abilities than those with only technical skill (Mathews & Bailey, 1965). They further go on to cite the existence and success of a formal training program in existence since 1937 at General Electric to encourage creativity within graduate engineers as evidence that creativity can in fact be enhanced by instruction (Mathews & Bailey, 1965).

Although the course described by Mathews & Bailey stops short of encouraging extensive problem finding by students it does contain the seeds of such an idea. For example, students are asked to "Submit an idea for measuring when highway signs need cleaning" (Mathews & Bailey, 1965). While this pre-supposes that the problem is the highway department needs a system for keeping track of when signs need to be cleaned there are other possibilities. The creative student in examining this dilemma might instead ask how the signs get dirty in the first place or if there isn't a way to reduce or eliminate the need to clean signs. This type of problem finding, though not explicitly included in the course, would seem to be encouraged as a creative solution to the problem. There is one project in the course where the students are expected to find and solve their own engineering problem. Towards the end of the course students are asked to form groups and then select and solve an electrical engineering problem which has not yet been solved or to make a major improvement in an existing solution (Mathews & Bailey, 1965).

Pappas (2002) too believes that creativity is at the heart of engineering but has been largely neglected by schools. Citing the increasingly complex issues which engineers are asked to address as well as the changing nature of technology and a complex society he believes that engineers can benefit from the type of creative thinking which has can bridge between engineering concepts and real-world problems. Despite the calls for innovative engineers by industry Pappas believes that engineering schools have been slow to respond. It is suggested that classroom activities such as reflection, writing, visualization, brainstorming and non-argumentative conversation support the development of creative problem solving skills and creative thinking (Pappas, 2002).

In their study of creativity in design Dorst and Cross (2001) note the importance of defining and framing the problem in the development of creative design solutions. They further indicated that “The designer decides what to do (and when) on the basis of a personally perceived and constructed design task…The creativity of the design is thus influenced by all these factors.” (Dorst & Cross, 2001). In other words, the designers individually found and reformulated the dilemma they were given and this was a critical step in the design of creative solutions which evolved simultaneously with the designers’ understanding of the problem.

Engineering educator and researcher Richard Felder (1987) believes that the most troubling problems facing society today “how to provide all our citizens with adequate and affordable food, housing and medical care, efficient and economical public transportation, clean and safe energy" (p. 222) will require creative problem solving on the part of engineers. Furthermore, he suggests that those responsible for educating future engineers, the engineering faculty, should be responsible for ensuring a supply of creative engineers or at the very least not discouraging engineers from being creative. Yet, he believes that for all the talk of problem solving and critical thinking there has been little movement in engineering schools away from the traditional methods of doing things where students are given lectures, homework and quizzes which revolve around well-defined problems (Felder, 1987). Although this method for presenting information is efficient on the part of the instructor it does not encourage creativity on the part of students and leads them down the path of relying on facts and laws rather than the development of new and creative ideas with the potential for lasting impact. Along with other activities aimed at encouraging creativity within his students one of the questions which Felder (1987) often gives to his students is to come up with a problem where specific engineering concepts might prove useful. This type of backwards question in which students are asked to find a problem is indicative of the creative thinking Felder wishes to encourage.

In much the same way that creativity has formed a backdrop for the study of engineering and design in the professional fields so too must creativity inform the field of engineering and technology education. Students seem to be both motivated and interested in the ability of engineering and design to solve real-world problems in creative ways. Curiously, one of the issues listed by Matthews & Bailey (1965) in their creative problem solving course was that students became too interested and involved in their course to the extent that excessive time was being spent and other coursework neglected. Although there has been a focus on engineering science in schools of engineering there is some evidence of backlash against this and technology education must be careful about embracing the fact-based and exact nature of science and engineering when the ill-structured and complex problems which we expect and hope that engineers are able to solve are frequently aided by the inclusion of creativity rather than mere technical skill. We must also see the motivational nature of creativity in the curriculum; one must only look as far as the children's literature section of a library and the popularity of books and projects in the style of Rube Goldberg to see that the interests of children are captured by the creative solutions to everyday problems.

Creativity in art

Perhaps the most quintessential discussions of creativity revolve around art. Artists and musicians have been identified as "creative people" for centuries and have become forever tied to the literature on creativity and problem finding because of their selection as subjects for a landmark longitudinal study by Jacob Getzels and Mihaly Csikszentmihalyi (1976). Their study began as an attempt to determine what indicators of future success, which in the art world is often based on perceived creativity of the artist, might be indentified in art schools students but what they ended up with surprised even them.

Getzels & Csikszentmihalyi noted that in order to truly examine the creative nature of artists they would need to look beyond the finished products and observe the creation of art (1976). Beginning with students at the Art Institute of Chicago, students who had made a commitment to becoming artists, they began to explore the process of creativity. Although there was some existing literature on the creativity of artists it was at best vague and tended to describe creativity as a subconscious impulse which is somehow translated onto the page. Investigators of creativity had usually started by observing the response to a presented problem, a tactic that Getzels & Csikszentmihalyi decided would not work. Instead, they focused on the development of the problem which is often where creative thinking begins. It is in this stage of problem development where creativity takes hold and a problem is found which leads to a creative solution (Getzels & Csikszentmihalyi, 1976). With this in mind Getzels & Csikszentmihalyi set about studying creativity based on the problem finding of artists.

What they discovered was more than knowledge, technical skill or craftsmanship what set apart successful artists from those less successful was their ability to find problems (Getzels & Csikszentmihalyi, 1976). Even more so than as a longitudinal predictor the art students who showed evidence of a problem finding process produced more creative works than their counterparts who viewed art creation as a problem solving process (Getzels & Csikszentmihalyi, 1976).

The results of the Getzels & Csikszentmihalyi study have profound implications for the inclusion of engineering design in the technology education curriculum. Lewis (2005b) has suggested that creativity is the underpinning of much of what we do in technology education, particularly the design and problem solving aspects encouraged by the *Standards for Technological Literacy* (International Technology Education Association, 2000). Lewis (2005b) argues that design gives us reason to step outside of traditional well-structured problem solving approaches and into creative solutions. If we are indeed seeking to encourage students to find novel and appropriate solutions to the dilemmas with which they are presented problem finding will need to be a critical aspect of the curriculum although thus far it has been largely neglected (Lewis et al., 1998; Lewis, 2005b).

Summary

The increasing importance of engineering and engineering design within the technology education field presents new challenges for the technology educator, particularly as it related to the development and assessment of new curriculum. Successful engineers are able to deal with ambiguity, uncertainty and understand the broad implications of their designs and successful engineering education curriculum addresses these areas. Engineering design has been presented as a specific case of problem solving which begins with the problem finding or scoping process and which drives the selection and quality of the ultimate solution.

Another mark of quality engineers is the ability to find creative solutions. Creative solutions, as a goal of the design process, are encouraged through the exploration of creative problems. The idea of problem finding is not unique to engineering education. Education researchers from the math and science fields have been exploring the benefits and relationships of problem finding at the K-12 level for a number of years.

Problem finding researchers have utilized many different methods of assessing problem finding ability. The most common assessments of problem finding ability have relied on paper and pencil instruments which are scored by a panel of trained judges on one or more measures of creativity including flexibility, fluency, originality and elaborateness.

Chapter III

Method

Keeping in mind that solving complex and ill-structured problems is a major tenet of engineering and technology education curricula and that this requires the problem solvers have the ability to define and question the problem itself through a process of problem finding it is the goal of this study to explore the influence of engineering and technology education courses on the problem finding ability of engineering and technology education students. It is this goal from which the four guiding research questions were derived:

1. How do the problems identified by students at three Minnesota high schools compare on known measures of creativity?
2. Does gender make a difference in the types or creativity of problems posed by students from three Minnesota high schools?
3. Does coursework or curriculum make a difference in the types or creativity of problems posed by students from three Minnesota high schools?
4. What do the problems posed by students at three Minnesota high schools reveal about their understanding of the nature of engineering?

This chapter will examine the methodology and procedures used in this study through the lens of related areas of study. The chapter consists of two primary sections. The first section will explore methodologies and procedures used in the past for the study of creativity, design, and problem posing; the three areas of research most closely associated with this study. The second section will provide details about the procedures and method used in this study including information about the variables measured, the setting and the instrument used.

Methods for studying creativity

Interest in the measurement of creativity is something which developed primarily in the second half of the twentieth century. Prior to this creativity had been considered the domain of the genius and a mysterious process which could not be fully understood. If creativity was an inherited trait or one received by chance there would be little purpose in measuring it beyond the worth of the products created. Once creativity began to be viewed as a valuable social trait to which all might aspire and interest arose in the teaching and nurturing of creativity there was an explosion of interest in the measurement of creativity so that these efforts to teach and nurture creativity might be evaluated (Mooney & Razik, 1967).

Before one can begin to measure creativity there must be a definition which clarifies what about creativity is to be measured. In Guilford’s (1950) seminal article on creativity he suggests that creative behavior consists of activities such as inventing, designing, contriving, composing, and planning. Based on his work other researchers such as Hitt & Stock (1967) indicate that originality is the primary concern of creativity an idea expanded on by Goldman (1967) who describes creativity as original, inventive and novel ideas.

If original, inventive and novel ideas are the outcomes of creativity we are still left at somewhat of a loss on how to measure these ideas as they are, at least to some extent, subjective measures which vary not only by evaluator but by time and place. For example, using the Earth’s magnetic field to tell direction was no longer novel in Asian cultures by the time it was ‘discovered’ by some creative Europeans. Although it can be difficult to reconcile these differences in time and place when measuring creativity there has been much work done addressing the concerns of subjectivity.

Much of the early work in creativity involved the use of traditional measures of achievement such as school grades and traditional intelligence testing (Taylor & Holland, 1967). From a procedural standpoint these would make ideal measures of creativity as there had already been significant research on measures of educational assessment. Unfortunately, both school grades and intelligence proved to be poor predictors of creativity as they do not often center on or reward creative activities (Taylor & Holland, 1967). Instead, there would need to be new measures of creativity developed.

After much analysis of intelligence tests and their relation to creativity researchers such as Guilford and Thurstone began to see creativity as the combination of multiple factors which could be measured separately (Taylor & Holland, 1967). Guilford (1959) identified some of these factors as originality, adaptive flexibility, spontaneous flexibility, ideational fluency, expressional fluency, associational fluency, word fluency, sensitivity to problems, visualization, judgment and redefinition. Guilford’s factors, to one degree or another, seem to have been generally adopted as measures of creativity by other creativity researchers (Burkhart, 1967; Goldman, 1967; Taylor & Holland, 1967).

With the measures of creativity defined researchers could develop specific tests for creativity. Taylor & Holland (1967) describe the use of word association, describing uses for things, identification of hidden shapes, fables, makeup problems, inventive manipulation, identification of alternative solutions to frustrating situations in well known children's stories, ask-and-guess tests and match problems as specific tests which have been used to measure creativity. These tests are not without problems though. Goldman (1967) notes that tests of creativity which encourage divergent thinking are often difficult to score because there is not a constrained set of factually correct answers. Guilford (1967) underscores this difficulty and notes that much of the measurement of creativity relies on the subjective judgments of observers. One method of improving reliability suggested by Goldman (1967) and Guilford (1967) is the use of a panel of well-instructed raters on measures of creativity. This solution was implemented as jury panels by Getzels & Csikszentmihslyi (1976) in their seminal study on creativity in art.

Methods for studying engineering design

Although many researchers have studied the engineering design process, much of their research has been confined to structured interviewing, observation and verbal protocol analysis (Atman, Chimka, Bursic, & Nachtmann, 1999; Cross, 1999). While these types of studies can provide a great depth of knowledge about the design process they tend to focus on understanding the process through a very small group of designers and not on surveying the abilities of a large group. The goal of this type of research seems more to be the identification and exploration of a design process or model than determining who is good at design or why they are. Furthermore, although there is recognition among design scholars that engineering design is a type of problem solving there have been few studies which specifically examine this link or discuss the problem finding aspect of engineering design.

The most common method for studying the design process appears to be think aloud verbal protocol analysis (Atman et al., 1999; Dorst & Cross, 2001). This type of research involves participants verbalizing thoughts and actions as they work through a design problem. Instead of asking the participant to reflect on the design process and thus distract them and introduce their own thoughts the think aloud process is designed to provide as little interruption as possible and allow conclusions to be drawn about the cognitive processes being employed by the participant as they go about their task. The recorded protocols are transcribed then segmented and coded by the researcher in an effort to analyze the design process or methodology.

A typical verbal protocol analysis study such as Atman et al. (1999) includes coding for the design step, current activity of the participant, type of information being processed and object being considered. These coded protocols are then analyzed depending on the specific nature of the research questions. For example, in the Atman et al. (1999) study they were primarily concerned with differences in the design stages used by freshmen and senior engineering students as well as the amount of time students spent in each of these design stages.

Methods for studying problem finding

Research on problem finding has not been solely the domain of either quantitative or qualitative research though there is some preference for quantitative methods. The preference is understandable when it is considered that research on problem finding grew out of research on problem solving undertaken by educational psychologists. Even those studies which employ data collection methods often associated with qualitative studies such as interviews and observation are frequently quantified for analysis of problem finding.

Much of the foundational research in problem finding has been conducted using what might be called quantified observation. This technique relies on observation of the problem finding process in a way which is eventually quantified for further analysis. For example, Allender (1969) studied the problem finding ability of elementary school students using this technique.

In the Allender study the students became the simulated mayor of a small town and had to address those issues common to this line of work using the documents and information provided by the researcher. The students were observed as they went about the process of playing mayor and the amount of time they spent looking at various documents was recorded by observers. These ‘inquiry times’ were then analyzed by the researcher who drew conclusions about the willingness of students to engage in problem finding behavior without external feedback.

Another example of quantified observation can be found in the Getzels & Csikszentmihslyi (1976) study on problem finding in art. Participants in this study were observed as they created artworks from still life and their problem finding was quantified at various stages of the process. At the problem formulation stage problem finding was evaluated based on the number of objects manipulated, uniqueness of the objects chosen and exploratory behavior during selection and arrangement. The uniqueness score was inversely related to the number of artists who chose to work with particular objects so that a higher score corresponded with objects less frequently used and exploratory behavior was scored based on a rubric where the more closely an artist examined potential objects the higher their score (Getzels & Csikszentmihalyi, 1976). Other scores such as openness of problem structure, discovery-oriented behavior, changes in problem structure and content are recorded in a similar manner. Although Getzels & Csikszentmihslyi did conduct interviews with their participants related to problem finding the answers to their questions were quantified for further analysis.

Not all research in problem finding is strictly observational or reliant on interviews though. In a thesis study at Griffiths University in Australia researcher Peter Tracy (2005) utilized verbal protocol analysis to study the problem finding ability of high school industrial design students in Queensland schools. Participants in this study were given an initial dilemma which they were asked to address by designing a device. As they worked through the design process they were asked to verbalize their thinking and this was recorded for transcription and later analysis by the researcher.

Although many researchers investigating problem finding including Getzels & Csikszentmihslyi (1976), Tracy (2005) and Allender (1969) utilize some from of observation or manipulative task to look at problem finding there have been alternative methods used. The most common alternative to these methods are paper and pencil instruments designed to elicit problem finding behavior from subjects. Paper instruments have been used by Chand & Runco (1993), Hoover (1990; 1994), Okuda, Runco & Berger (1991), Smilansky (1984), Lee & Cho (2007) and others. While the earlier work by Smilansky (1984) asked participants to develop progressive matricies test items which use simple geometric pattern matching. The thinking behind this was that it would eliminate prior knowledge and language skills which could complicate the measure of problem finding ability.

Just as with the study of problem solving which initially focused on well defined and well understood puzzle-type problems in an effort to understand the nature of problem solving but from which grew a later pushback from researchers who saw this as unauthentic and not transferring well to real world problem solving of ill-defined problems so has a pushback been seen in problem finding. Not all researchers agree that creating problem finding tasks devoid of context will significantly advance our working understanding of problem finding ability. Okuda, et al. (1991) followed by Chand & Runco (1993) make specific mention of using real-world problems which participants can relate to as part of their research strategy. Along similar lines, the work of Lee & Cho (2007) asks students to devise a problem for study given a broad area of inquiry. In this case students are familiar both with the material which is locally relevant and the devising of a problem for study which is frequently needed by students in the school setting.

Design of this study

As has been noted in previous chapters there is a great interest in developing the real-world problem solving ability of students, something which is seen as imperative both for their individual success as well as our success as a nation. If students are to fully realize their potential as creative problem solvers they must have a school experience and curriculum which supports that goal. As we have also learned, the finding of the problem to be solved given an initial dilemma is a key aspect which sets the tone for the entire problem solving process as well as the eventual success or failure of the solution. Therefore, it is critical that a method exist for the comparison of problem finding across curriculum and environments which purport to aid in student learning of critical problem solving.

Variables and instrument design

Before this study could be undertaken a suitable instrument and method for the evaluation of engineering problem finding ability needed to be developed. The design of this instrument was driven by several factors. First and foremost, the data collected needed to support answering the three guiding research questions. This necessitated the collection of certain demographic data including gender and coursework history for engineering, advanced science, and technology education classes taken in high school. It also meant devising some method of capturing and measuring the ability of students to find engineering problems. Secondly, the design was influenced by the need to gain acceptance of both the University of Minnesota IRB and individual school and district gatekeepers. This suggested a completely anonymous data collection method and instrument. A copy of the instrument is included in Appendix A.

Because of the lack of prior studies on engineering problem finding the development of this section was a combination of the many methods used in the past to study both engineering design as well as creativity. From engineering design literature came the idea of presenting design challenge scenarios and asking students to identify problems that they might choose to address if they were an engineer faced with the situation. From the creativity literature came the method for converting student responses into quantitative data, a process which will be described in more detail later.

The two scenarios themselves were selected for several reasons. As suggested by Hill & Smith (1998) authentic educational experiences are critical for students. This means that the scenarios should be both realistic and familiar to students. The scenarios must be accessible to the participants, in this case high school students from a variety of backgrounds. This meant that the scenarios should be understandable and common enough that students would have a good idea about what issues might come up. Secondly, they should be interesting to the participants in order to engage them in the problem finding exercise as much as possible. Thirdly, they should be issues that might be realistically encountered by a practicing engineer. Fourth, the issues should not be so complex or numerous that they cannot be fully discussed by an average student in a single class period.

These four criteria drove the selection of two scenarios to be included in the instrument. Both were selected because they fit all three of the criteria reasonably well. The first, an issue related to energy efficiency, was both timely and accessible because of rising energy costs and frequent media attention to the problems that wrought. It is also well known that engineers address issues of energy efficiency. Indeed, many engineering schools take part in the US Solar Decathlon event which specifically relies on energy efficiency as a measure of success.

The second scenario selected related to the river flooding of a fictional town. Students in Minnesota, where this study was administered, are frequently made aware of flooding problems along rivers by the media and many may have had personal experience with some kind of flooding. In addition to it being well known that engineers work on hydraulics and water problems respected engineering design researcher Cynthia Atman has used the issue of flooding to examine the design process of engineering students.

Data from five variables were captured through the paper and pencil test instrument which allowed for more students to participate and facilitated the later scoring of responses. The two primary areas into which these variables fall are background demographic data and measures of problem finding ability. Gender was one of the demographic factors useful in describing the type of problems identified by participants and to account for additional variability within the statistical model.

Schools and students

Although no identified literature has examined the differences in problem finding ability based on school environment there is some anecdotal evidence that differences may exist. In discussing the dearth of applicants to engineering schools many engineering faculty lament the decline of the so-called ‘farm mechanic’ which made up much of their admissions in the last century. The belief is that rural students with farm experience often need to make do with what is available to them as they go about solving a variety of engineering design problems such as the flat tire problem discussed in the first chapter. Urban and suburban students would be more familiar with getting things done the ‘right way’ and often have more nearby resources to draw on making them less apt to devise creative solutions to problems. Students from three different schools were administered the problem finding test in an effort to obtain results from different types of student populations.

School 1 was an outer ring suburban high school from the Minneapolis/St. Paul area which participates in the Project Lead the Way engineering curriculum as well as offering advanced science and traditional technology education classes. The students taking part in this study came from one of the Project Lead the Way classes though some had previously taken advanced science or technology education classes.

School 2 was a rural/small town high school in south central Minnesota which does participate in Project Lead the Way, but only on a limited basis. When data for this study was collected in Fall 2008 there were no Project Lead the Way classes currently underway and the students came from two sections of traditional technology education classes.

School 3 was a first ring suburban high school from the Minneapolis/St. Paul area which does not currently participate in Project Lead the Way and offers no technology education classes of any kind at the high school level. The school is known for high academic standards and has been a leader in Advanced Placement and Enriched science education. Students from this school came from two sections of Advanced Placement Physics.

The third demographic variable collected was the type and number of courses and curriculum the participant has been exposed to. Students were asked to list all of the engineering, advanced science courses and technology education courses they have taken in high school. Many of the engineering and technology education courses purport to teach problem solving skills which have been identified as important outcomes but there is little known about if students who take these courses actually do better than their peers when faced will an ill-structured real-world challenge.

Specific details about the participant makeup is included in Table 1, Table 2 and Table 3.

Table 1.

School Demographics for Scenario 1

		Number of Engineering Classes		Number of Advanced Science Classes		Number of Technology Education Classes	
	N	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
School 1	21	1.52	0.680	0.76	1.044	1.38	1.322
School 2	33	0.00	0.000	0.00	0.000	1.55	0.833
School 3	37	0.00	0.000	3.16	1.482	0.00	0.000

Table 2.

School Demographics for Scenario 2

		Number of Engineering Classes		Number of Advanced Science Classes		Number of Technology Education Classes	
	N	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
School 1	21	1.52	0.680	0.76	1.044	1.38	1.322
School 2	33	0.00	0.000	0.00	0.000	1.52	0.834
School 3	36	0.00	0.000	3.19	1.527	0.00	0.000

Table 3.

Gender Demographics

		Number of Engineering Classes		Number of Advanced Science Classes		Number of Technology Education Classes	
	N	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Scenario 1 Females	15	.13	.352	3.13	1.807	0.20	0.561
Scenario 1 Males	75	.40	.771	1.15	1.608	1.01	1.121
Scenario 2 Females	15	.13	.352	3.13	1.807	0.20	0.561
Scenario 2 Males	74	.41	.775	1.14	1.633	1.01	1.116

Note. One student failed to report a gender and so is excluded from this table.

Finally, student identified problems were collected from the two simple but real-world and ill-structured situations described above which call for engineering design and problem solving. Participants were asked to identify problems in these situations which, if solved, would significantly improve things.

Reviewers

The creative problem finding ability of participants was evaluated based on the same measures used by Lee & Cho (2007) and which are further supported by the methodologies commonly used by creativity researchers. The problems identified by participants were evaluated by a panel comprised of researchers and educators familiar with engineering design or technology education following detailed instructions, rubrics and training.

Reviewer 1 was a female graduate student from the University of Minnesota department of Mechanical Engineering. She has been a teaching assistant in the undergraduate mechanical engineering capstone design course for some time.

Reviewer 2 was a male former high school Project Lead the Way teacher now teaching middle school Project Lead the Way classes. As a high school teacher he spent several years teaching the Project Lead the Way "Introduction to Engineering Design" class and is also familiar with technology education.

Reviewer 3 was a male graduate student from the University of Minnesota department of Mechanical Engineering. He also has been a teaching assistant in the undergraduate mechanical engineering capstone design course for some time.

Each of the two scenarios completed by each participant was scored independently by the three judges on four measures of creativity. Judges were instructed to read through a sample of student responses to gauge the range and types of responses they would encounter during the rating process. The actual rating process had five key steps for each scenario. The complete judge instructions are included in Appendix D.

1. After reading the entire student response for the given scenario the judge gave the student an overall rating on *fluency* with assistance from a rubric. Judges were instructed to rate fluency based on the number of problems identified by the student compared to all other students for the given scenario. This rating was on a five point Likert type scale.

2. Judges then determined the number of broad categories the problems fell into and rated the student on how many different categories their problems came from. Judges were instructed to rate *flexibility* based on the number of problems identified by the student compared to all other students for the given scenario. Again, a rubric was provided to assist judges. This rating was on a five point Likert type scale.
3. For each of the individual problems identified by the student the judge first determined if it was an *appropriate* problem for the given scenario. This rating was a Yes/No dichotomous variable. Those problems which did not appropriately address the scenario were removed from the study. This follows the advice of Lee & Cho (2007) who note that it is easy for evaluators to determine whether a problem is appropriate but extraordinarily difficult to assess and place a score on the degree of appropriateness.
4. Assuming that the individual problem was appropriate judges were asked to rate the *originality* of the problem compared with other students. The more common a problem was the lower the originality score judges were to give it. This rating was on a five point Likert type scale.
5. Finally, judges were asked to evaluate how thoroughly the student *elaborated on the specific problem* they identified. This rating was on a five point Likert type scale.

Getzels & Csikszentmihslyi (1976) noted in their study the usefulness and appropriateness of evaluation panels for research on problem finding. Similarly, Guilford (1967) noted that most research on creativity involves some measure of subjectivity and is dependent on the judgments of others but that these judgments have been more predictable than most other criteria. The data on interrater reliability, calculated as Cronbach's alpha following the data collection period, seems to bear out this for the most part. Interrater reliability is presented in Table 4.

Table 4.

Interrater Reliability Statistics

		Cronbach's Alpha			
	Cases	Fluency	Flexibility	Originality	Elaborateness
Scenario 1	91	.917	.814	.703	.836
Scenario 2	90	.922	.835	.877	.896

Note. N = 3 reviewers for each scenario.

With the sole exception of originality in scenario one all of these alpha statistics meet the .800 level frequently suggested as a standard for interrater reliability. Given the subjective scoring utilized by the panel and the diverse backgrounds of panel members these values are quite good.

Data analysis

Analysis of the data collected from students and, ultimately, judges was complicated significantly by the free response nature of the ill-structured situations. In an effort to capture as clear a picture as possible from the data available two distinct approaches were used.

First, the panel of judges was asked to rate the problems identified by students on the four factors of creativity: flexibility, fluency, originality and elaborateness. The student response sheets provided to judges contained none of the demographic data about students and the only indentifying marks were unique student identifiers which were assigned by the researcher. The judges were provided with both written and oral instructions as well as a rubric to assist them in this task. A copy of all scoring instructions and this rubric are included in the appendices.

Because students did not specifically number or list all of the problems identified and also may have included sketches, drawings or diagrams it was up to judges individually to determine where to separate problems identified by students. This led to different judges determining a different number of problems for the same student response. While this was not problematic for the flexibility and fluency scores which are per student, per scenario it was something that needed to be dealt with for originality and elaborateness scores which were per problem. The solution eventually employed was to average the originality and elaborateness scores across all appropriate problems identified by the student. In this way for each scenario each student ended up with a single score for each of the four characteristics (fluency, flexibility, originality and elaborateness) from each judge.

These scores were subsequently entered into a spreadsheet along with unique identifiers and quality checked. At this point judges were contacted about any missing data and asked to re-score those students for whom they were missing data. Most of the judges responded promptly and those corrections were made to the spreadsheet. One of the judges was unable to provide corrected data and so all students missing data from that judge were removed from the data set. Specifically, this meant excluding two students from the first scenario and four students from the second scenario because one or more of the creativity characteristics were unscored. This does mean that while the same students responded to both scenarios the students included in the quantitative analysis are slightly different for the two scenarios.

Following the quality check of the data it was copied into SPSS for interrater reliability analysis. At this point each student in each scenario had three scores for each of the four creativity characteristics, one score from each judge. The RELIABILITY program was used within SPSS to determine the interrater reliability statistics given in Table 4. Once interrater reliability had been ascertained the statistical analysis could be continued.

Because the research questions revolve around differences due to the demographic factors of school, gender and coursework history and not around differences between judges the data needed to be further manipulated to arrive at a single score for each creativity characteristic for each student in each of the two scenarios. This was done by averaging the three fluency, flexibility, originality and elaborateness scores for each participant. In this manner each student ended up with a single value for each of the four creativity characteristics which, when combined with the demographic data, could be further analyzed.

The first statistical analysis employed was the MANOVA procedure which examined differences in the four creativity characteristics based on the school and gender of participants. Secondly, differences because of coursework history were explored using the multiple regression procedure because of the continuous nature of that variable. Both procedures were carried out independently for the first and second scenario. The results of these procedures can be found in the following chapter.

In addition to the statistical analysis of data from the judges a more qualitative method was used to evaluate common categories among responses by categorical variables. These qualitative observations were meant to be purely exploratory in nature but to catch any possible differences in problems found at the different schools as well as by female and male participants. For the first analysis student responses were sorted by school. All responses for one scenario at a time were read by the researcher and notes taken on the broad themes which seemed to categorize the majority of responses. This type of fuzzy and subjective analysis was required because of the many ways and many levels of detail with which students identified problems. At the same time specific examples of problems within these broad categories which exemplified the category were recorded for use within the results section. This process was repeated for each of the three schools and for the second scenario.

Once this was complete the student responses were re-sorted based on the gender of the participant. The same process was employed for determining the broad categories of responses within each gender.

After a complete list of common problem categories was determined for each school and gender by scenario the lists were compared for similarities and differences. The list of categories itself was coded to identify both similar and unique categories of problems amongst the three schools and again between the two genders. These coded category lists were used during the discussion of qualitative results in the following chapter.

Chapter IV

Results

The data were collected from each of the three schools and turned over to the three judge panel as described in the preceding chapter. In addition, student responses were qualitatively evaluated for response categories by the researcher as described in the previous section. Each of the two scenarios was treated separately and is presented here in that way. First, the energy efficiency scenario will be examined through the lens of the research questions. This will be done both qualitatively through a discussion of categories in student response and quantitatively through MANOVA and Multiple Regression statistical analyses. Next, the flooding scenario will be examined in the same way.

Scenario 1: Energy Efficiency

Students from School 1 and School 3 had generally similar ideas about improving the energy efficiency of homes while students from School 2 took a rather different direction. There were some ideas which were mentioned frequently by students in all three schools. Specifically many students mentioned installing or upgrading insulation as a key method for reducing energy consumption. Beyond this; however, there were some distinct differences.

While the scenario presented to students specifically mentioned that the houses were in the design stage, i.e. not yet built, only students in schools 1 and 3 frequently suggested modifying the architectural layout or design of the homes. Specifically students from School 1 suggested design modifications such as reducing ceiling height to reduce the volume of conditioned air and students from School 3 suggested designing homes to better take advantage of sites such as through the use of passive solar heating in the winter. Students from both schools mentioned the overall size of homes as a contributing factor to energy inefficiency and suggested redesigning homes to be smaller and more efficient. Table 5 and Table 6 present example student responses from schools 1 and 3 for this scenario organized by categories found in the responses of the school.

Table 5.

Scenario 1 Example Student Responses from School 1 by Theme

Theme	Example Responses
Alternative energy	• "Energy could be saved by using solar power on the roofs…a stream or river could help power the homes as well" • "The cost of electricity can be high. This problem can be solved in a variety of ways. A good way to solve this is to install a wind turbine (or a few wind turbines) that can provide electricity for an entire neighborhood or city. In this way, the cost will be spread among many people." • "New energy ideas can also be explored. If at all cost efficient the firm could look into solar or wind power (or others) to power the house."
Insulation	• "To improve the energy efficiency of the homes you could make the walls thicker so you can put more insulation in them" • "Heat rises therefore the first step to energy efficiency is to make sure the roof is well insulated" • "The house blue prints must try to make a design that will be easy to heat, cool & insulate"
Redesign for better heating and cooling efficiency	• "A big problem with energy efficiency is heating and cooling costs. The best way to deal with that is build a house with a minimal amount of exposed surface area…" • "The house should also be south facing if possible to help with heating costs in the winter" • "The very tall ceilings are a problem when the homeowners are trying to heat and cool the houses. Because heat rises, it will build up from the top

	down and will take much more time and energy to keep the house heated.”
Heating/Ventilation/Air Conditioning (HVAC) efficiency	• “As for cooling, cold air will sink, so although the area that the people are lining in is cool, the air will continue pumping in until the full room is cool. I would advise lower ceilings, but since the house is already built, placing the air vents half-way down the wall, instead of at the top so the cold air will not need to fill the whole room would be a good start.” • “The efficiency of the furnace + AC is also important” • “If the home buyer wants to be able to keep the whole house heated, then the heating system should be lower or on the floor as shown in the poor drawing. If the vents are low the heat will have to travel through the air and up to the ceiling.”
Things left plugged in or turned on	• “Problem – appliances and electronics such as TVs and computers still draw power when they are turned off or nobody is home. Solution – to prevent devices such as chargers from drawing power when not used, create some sort of device which plugs into an outlet which allows other cords to be plugged into it. When the amount of power being used drops below a certain threshold, the device cuts off power consumption completely, preventing electricity going to waste. To prevent power consumption from something such as a light being left on when nobody is home, create a device that allows the user to in some way be reminded of what is using power in their home, and if possible, remotely terminate the thing using power.” • “Have multiple light switches for same thing to increase ease of shutting off lights for occupants so as not to waste electricity.” • “Another issue making them inefficient could be the fact that the heat is left on even when there are no people home. A simple solution to this is to have a programmable thermostat installed in every home and encourage the homeowner to use it.”

Table 6.

Scenario 1 Example Student Responses from School 3 by Theme

Theme	Example Responses
Alternative energy	• "Gas is very expensive, due to the economic downturn and high energy use. In addition, heating a cooling is inefficient (especially through use of gas). Instead, solar panels should be utilized on the roof of the house. They are more environmentally friendly and make houses look more fashionable. Renewable energy could heat and provide power to the home." • "Solar power panels on roofing if there is enough sun. Nearby wind farms = renewable energy source, hydroelectric power. All of these would give more room for increasing efficieny." • "Invest in solar panels. By producing its own clean energy during the day the house could minimize dependency on unclean, expensive energy services."
Insulation	• "Heating is a big energy cost so if we cut down on loss of energy to the outside we can save money, adding insulation would help this problem" • "Houses should have a better insulation structure to keep heat in when it's cold and expel heat when it's warm to reduce the reliance on less efficient air conditioning units/water heaters." • "Work on creating a more insulated house, double front doors for the trapped air in between to insulate the house, and the double paned glass throughout the entire house for more pockets of air/insulation."
Appliance efficiency, mostly related to HVAC systems	• "Using geothermal heat to heat and cool the house would save energy. Since the heat of the earth below the surface is relatively steady in comparison to the fluxuating temperature above the surface. So if we can pump water down through tubes, have it heat up we can raise it back up to hear our homes cutting down on energy costs. It can also be used to cool houses in the summer." • "The methods by which homes are heated and cooled remain extremely inefficient, despite technological advancements. Individual boilers to heat homes requires the constant heating of water, even if not used. Instead, one could implement a communal boiler, much like power from a power plant."

	• "Architectually, design houses in such a way that the source of energy is close to the center, so less is lost as it gets to its destination. Put air conditioner/heater in the middles of the house rather than blocked off in the basement. Make houses more compact so the energy has to travel less far."
Home size	• "The best way to conserve energy would be reduce house size (reducing leaks of heat)." • "Problem: houses are too big Solution: build homes with less air space, lower ceilings, etc." • "As for actual construction, houses should be built smaller, this would require less materials, and less energy to power."
Occupancy sensing	• "Lights could also be controlled by vocal commands. It would be easier for homeowners to turn off lights, so they would conserve more energy." • "Lighting: They could have motion detectors for rooms so that they turned on only when someone enters and then turned off when there isn't movement." • "Also, having a way to turn the heat down when people are at work or away would save energy. If there is a way for the heat to turn back on at a predetermined time then people could come home and never have to deal with the heat. It could save energy and not be a hassle to the owner"

On the other hand the responses from School 2 tended to be briefer and more focused on things that a homeowner could change after the home was built rather than on changing the design of the home. For example, many students from this school suggested alternative lighting technologies, specifically compact fluorescent and light emitting diode based lighting as replacements for traditional tungsten light bulbs. These students also frequently discussed changing out windows for more efficient ones and ensuring that contractors did not cut corners when building the home. Overall, the responses from School 2 were less thorough in the quantity and quality of responses as well as focusing more on behaviors of the homeowner and builder than on the homes themselves. Table 7 presents example student responses from school 2 for this scenario organized by categories found in the responses of the school.

Table 7.

Scenario 1 Example Student Responses from School 2 by Theme

Theme	Example Responses
Lighting inefficiency	• "Install fluorescent light bulbs in the rooms you use most." • "Install more efficient lighting" • "fluorescent lightbulbs"
Geothermal	• "geo-thermal" • "use floor heating – geo-thermal heating" • "replace all light bulbs with geo thermal ones"
Voltage loss	• "Extra cable length: Sloppy workmanship by the electrician wiring the house also adds to the home owner's bill. Untidiness may result in additional cable length, adding resistance, reducing ampacity, and drawing more electricity" • "Somehow find a way to manufacture cheap superconductors for wiring. The less resistant the conductors are, the more efficient they become." • "Electrical: In an old home you could replace old lighting recepticales and wire with new upto date recepticales & switches. It will meet code and have a better electrical efficiency rating."
Appliance efficiency*	• "Use lower watt appliances" • "I would solve energy by getting efficient appliances" • "If you don't have energy star appliances that could greatly affect your power consumption."
Insulation	• "Insulation: If you are planning to buy a home you should make sure that there is enough insulation needed in the attics & ducts so you don't have heat loss & energy efficiency" • "Better insulation to hold in more heat so you don't have to use the heater as much" • "add more insulation"

Window efficiency	• "One problem that could be fixed would be bad windows putting a cover over it so no heat would be lost. If that would be fixed then a heating bill would cost less." • "Put in some high grade windows. If you have poor quality windows you won't be able to keep heat in during the winter or cooler air during the summer" • "I would make sure all windows are replaced with low-e argon filled windows."

*This was mentioned much less than in the responses of school 3, but was a minor theme in responses

Differences also existed in the responses typical of female students when compared to the male students across all schools. Specifically, females were much more likely to mention the size and design of homes as problems contributing to energy inefficiency than their male counterparts. The females also frequently suggested that things in homes such as lights, electronics and heat get left on and continue to use energy when not in active use. One response typical of female students who mentioned things which are not in active use but continue to draw power looked like this:

> Problem: Energy is lost through electronics "sleeping" and on electronics while people aren't there, such as forgetting to turn off lights.
>
> Solution: Electronics such as TVs "sleep" while ppl don't use them. While sleeping they use small amounts of electricity to be ready to turn on at a moments notice and don't stop sapping energy unless unplugged. TO prevent this they power for those types of objects could be set on a timer, w/ no powerflow when ppl are sleeping or gone at work. To prevent electricity waste by lights left on when ppl are gone, the lights should be set to activation. Like clap-lights that turn on w/ a sound these lights will stay on if they "hear" a noise every 5-10 mins. w/

an option for manuel over ride if a person wants to read etc. This way if ppl leave the lights will turn off on their own.

On the other hand male students were more likely to discuss the efficiency of lights (when they are on) and suggest replacing them with more efficient illumination technologies. Many of the males also mentioned windows as a great source of heat loss which could be improved using new technologies. Students of both genders mentioned problems with insulation, heating and air conditioning systems, appliances and inefficient energy sources. Table 8 and Table 9 present example student responses for this scenario organized by categories found in the responses of each gender.

Table 8.

Scenario 1 Example Student Responses from Females by Theme

Theme	Example Responses
Insulation	• "Skimping on insulation from window, to floor, to wall, to ceiling, to roof all cause energy inefficiency that ends up increasing cost to the home owner in the long run." • "One problem a house may have with lower energy efficiency could be related to the heat lost due to poor insulation… Solution: I would use better insulation in the walls when building a house and get windows which better keep the heat in without leaking/lower amount of windows."
Occupancy sensors	• "When the sensors did not detect anyone for 5 mins the timer would be part of the wiring and it would turn off once it hit 5 mins breaking the circuit/power system to the lights." • "Problem – appliances and electronics such as TVs and computers still draw power when they are turned off or nobody is home. Solution – to prevent devices such as chargers from drawing power when not used, create some sort of device which plugs into an outlet which allows other cords to be plugged into it. When the amount of power being used drops below a certain threshold, the device cuts off power

	consumption completely, preventing electricity going to waste. To prevent power consumption from something such as a light being left on when nobody is home, create a device that allows the user to in some way be reminded of what is using power in their home, and if possible, remotely terminate the thing using power.”
Heating, Ventilation, Air Conditioning (HVAC) systems	• “Inefficient heating: Instead of having central heating that is transmitted via ventilation you could put a source of heat such as a fireplace or radiator in the middle of the house and build rooms around it.” • “Inefficient heating and energy dispersal: Since the heating system in a house is often not central, the heat goes to the rooms right around the source but has a hard time reaching the outer rooms. Heating systems should be the ‘foundation’ or ‘base’ of the house. The rooms should be built around that source to minimize unequal heating.”
Home size	• “The heating system may be inefficient because of heat loss especially when the house is big. The warm air goes up and leaves the lower part of the house cold. To heat up the whole house would take many hours and too much gas.” • “The best way to conserve energy would be to reduce house size (reducing leaks of heat).”
Alternative energy	• “Efficient heating and electricity could be improved with solar and wind energy. I’d get solar panels on the roof everywhere and some wind turbines on the trees to be more efficient. This wouldn’t look so bad because it’s only the roof and you could get some green wind turbines so it wouldn’t look so bad in the trees. Also you could use the heat energy produced by your body to power smaller appliances like toasters. This could be done by making a device connected to your skin.” • “Use solar power”

Table 9.

Scenario 1 Example Student Responses from Males by Theme

Theme	Example Responses
Insulation	• "Heating is a big energy cost so if we cut down on loss of energy to the outside we can save money, adding insulation would help this problem" • "To improve the energy efficiency of the homes you could make the walls thicker so you can put more insulation in them"
Lighting	• "Install more efficient lighting" • "Use LEDs of CFL lights wherever possible"
Heating, Ventilation, Air Conditioning (HVAC) systems	• "The furnace itself needs to be looked at to make sure that it will function properly. Air must be evenly distributed throughout the house to ensure satisfaction. The ductwork should have as little bends as possible since this can cause loss of air movement. If bends are needed then extra propulsion fans may need to be installed as well." • "Replace low/medium efficiency furnace/water-heater with a high efficiency model. Use multiple zone heating and cooling."
Appliances	• "I would solve energy by getting efficient appliances." • "Use energy star appliances for boiler, water softener, etc. have them centrally located within the house so as not to give bias to any room in the building."
Alternative energy	• "Energy could be saved by using solar power on the roofs of the new homes, as well as using power saving lights." • "Solar power panels on roofing if there is enough sun. Nearby wind farms = renewable energy source, hydroelectric power. All of these would give more room for increasing efficiency."
Window efficiency	• "High ceilings & lots of windows tend to lose a lot of heat making heating bills expensive." • "The main problem would be heating. A lot of heat is lost through windows and door frames. One could install windows with 2 layers of glass in order to increase their insulation. They could also use better sealants that would allow for less heat to be lost."

A multivariate analysis of variance showed no statistically significant differences in the four traits of creativity measured by the judges at the .05 alpha level for school, gender or a school/gender interaction. In addition to the MANOVA procedure the data was analyzed using multiple regression to explore differences in each of the four traits based on gender as well as the number of engineering, advanced science and traditional technology education classes reported by each student. The results of these multiple regression analyses for each of the three traits with significant coefficients at the alpha level of .05 are presented in Table 11, Table 12 and Table 13. The multiple regression analysis for originality was not significant at the .05 level. The average judge scores on measures of creativity by school and gender are presented in Table 10.

Table 10.

Scenario 1 Average Scores

	Flexibility	Fluency	Originality	Elaborateness
School 1	2.444	2.651	2.679	2.300
School 2	2.081	2.131	2.472	1.505
School 3	2.558	2.631	2.745	2.403
All Males	2.382	2.493	2.606	1.983
All Females	2.155	2.133	2.697	2.391

Table 11.

Scenario 1 Fluency

	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	SE B	β	
Constant	1.974	.239		.000
Gender	-0.733	.331	-.238	.030
Engineering Classes	0.474	.167	.297	.006
Advanced Science Classes	0.263	.084	.408	.002
Technology Education Classes	0.028	.135	.026	.836

Note. R^2= .188

Table 12.

Scenario 1 Flexibility

	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	SE B	β	
Constant	1.988	.224		.000
Gender	-0.617	.311	-.219	.050
Engineering Classes	0.281	.157	.192	.077
Advanced Science Classes	0.238	.078	.404	.003
Technology Education Classes	0.010	.127	.010	.940

Note. R^2= .146

Table 13.

Scenario 1 Elaborateness

	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	SE B	β	
Constant	1.976	.184		.000
Gender	0.120	.255	.050	.640
Engineering Classes	0.375	.128	.302	.004
Advanced Science Classes	0.094	.064	.188	.147
Technology Education Classes	-0.248	.104	-.301	.019

Note. R^2= .208

Scenario 2: Flooding

Although few of the ideas put forth by students at the various schools were unique to a school none of the categories were found frequently across all three schools. For example, students from both School 1 and School 3 suggested that one potential problem is having too much water flow through the river near the town center and proposed various water diversion schemes to route excess water around the town. Another problem identified by students from these two schools was buildings built too low which they suggested rectifying either by raising or moving the buildings. Few, if any, students from School 2 identified either of these as problems. One problem which was frequently identified by students from School 2 was a lack of dams and containment of water upstream, suggesting that dams and reservoirs be built to prevent flooding. This was a sentiment echoed by students from School 1 but mentioned much less by students from School 3. On the other hand, some problem categories were identified by students from School 3 and School 2 but not so much by students in School 1. An example of this is a lack of containment systems to protect the town such as floodwalls, dikes and levees. This is not to say that there were no unique categories of response in problems suggested by students at the different schools. Example responses from School 1 and School 3 are provided in Table 14 and Table 15.

Table 14.

Scenario 2 Example Student Responses from School 1 by Theme

Theme	Example Responses
Water diversion	• "One idea to harness the energy is to set in place a trench or pipe or transport system to move mass amount of water to other places. A pipe set in place 4 appr. Feet above normal river level would transport water to where it was needed…the farm needs the water so it is transported there." • "If it is found that the river is spring fed it may be beneficial to divert some of the streams to other bodys of water in the area. Obviously one would need to research and take into account the surrounding eco-structure when ever displacement of waster is involved." • "Creating other smaller rivers around the flooding river could divert most of the water away towards a lake or pong. New problems could then be created like flooding of the lake or pond or destruction of the ecosystem."
Moving things to higher ground or putting buildings on stilts	• "Buildings that have a potential of being flooded could be built on stilts. These stilts will hold the building off the ground as water flows underneath them in the case of a flood." • "If homes are close, they should be raised. Placed

	higher than the surrounding land.” • “Someone put buildings in the wrong spot. These buildings should be moved to higher ground and the land should not be built on.”
Dams	• “A small dam with a reservoir upstream of the town would help in that the flow of water would be regulated and could be controlled. However, dams can cause problems with the natural ecosystems, so this problem would have to be addressed according to the location of the dam.” • “There is a spot about 10 miles upstream that would be a prime spot to build a dam. There was a beaver dam up until a few years ago here, but it has since been destroyed and the beavers have left, which I believe is the reason that there is now an issue with flooding that was no there before.” • “Dams and locks can be built to control water flow.”

Table 15.

Scenario 2 Example Student Responses from School 3 by Theme

Theme	Example Responses
Wetlands	• “Plant a lot of plants that will hold off some water as it floods. They would prevent soil erosion increasing safety from water.” • “Problem: Not enough wetlands to absorb the rising waters. Solution: Promote the growth of wetlands, destroy dams, etc.” • “Flooding is a key part in forest ecosystems and a dam would hurt the agriculture industries. However creating a wetlands further upstream will create a new ecosystem, purifying the water and slow the water down so that it floods at a more constant pace instead of seasonal flooding. This will help the agriculture down river as the farmers can use the river water to irrigate their crops.”
Water diversion around city (often with reuse)	• “Flooding can be a real problem if the proper precautions are not taken. In the case of the farm, they could use the flooded water in a reservoir in order to help irrigate the farm. Homes could use this water (if controllable) to water their lawns and wash clothes/dishes/themselves (if clean).” • “Flooding is good for the eco-system just like

	periodic forest fires are good. So one could use river run off, by having vertical popes in the ground that would collect water and divert it towards farms or have it purified and reused in our water.” • “People can’t stop flooding from happening. Flooding occurs because people built homes and buildings on wetlands where it’s natural for flooding to happen. However, if we can minimize the impact of the floods so that people are not severely affected by them, it will improve many of their concerns. When flooding occurs it will take over the houses, businesses and farms so we can build a big pipe under ground that is usually empty but when floods occur, opens and lead the water to and aquifer. But before the water enters the aquifer there should be an extensive filter system that will clean the water.”
Moving Homes	• “Problem: Houses are too near the river. Solution: Move the houses further away from the river.” • “I would also suggest moving homes and businesses to higher ground so as not to be damaged by any flooding that may occur.” • “Trying to maintain housing along the river is unadvisable because buildings will promote erosion and suffer water damages.”
Floodwalls	• “You could build a wall that is strong enough that it could block the water from getting to the houses. Having a wall along each side of the river allows the river to grow higher and wider. The flood water would just flow with the rest of the river and won’t destroy houses/businesses.” • “Recently a new flood protection system has been built in London to prevent flooding. If a threat exists, a river-wide wall is lowered into place, preventing surges and damage. Provided the river isn’t freakishly wide, this strategy would work well” • “During safe seasons the river banks have short walls with periodic pillars, they create a small wall but nothing that would destroy the look of the country and become annoying.” But when the threat of flood occurs the pillars open on either side revealing tall metal interlocking plates which when extended run along tracks to the next pillar where they are fastened to create a water tight wall holding back the water.”

One example of a problem which was mentioned almost exclusively by students at School 2 was that rivers will inevitably flood but that the water did not drain away quickly enough. In those cases students proposed solving the problem either with supplemental drainage systems or sump pumps. An additional characteristic of the responses from School 2, a sample of which can be seen in Table 16, was that they tended to focus on problems for individual homes and businesses rather than on the overall situation. On the other hand, it was mostly students from School 3 who suggested looking upstream (both literally and figuratively) for the source of the issue with potential environmental issues exacerbating the amount or frequency of flooding. Specifically, many of these students pointed to loss of wetlands as a contributing factor in the severity and frequency of flooding.

Table 16.

Scenario 2 Example Student Responses from School 2 by Theme

Theme	Example Responses
Allow river channel to hold more water (floodwalls, dikes, increase depth)	• "Dam part of the river for a while and dig the other part deeper to decrease water height. Add more dirt to banks to decrease chance of water going over top" • For the flooding problems you should have the city or the town look at the river & do some surveying on what part of the river should be built up to make a higher bank for less flooding." • "First I would try to build up the river bank so it would take a lot more water to over flow."
Dams	• "You should maybe think about installing a dam system so you can control the height of the river when needed." • "I would have the city make a dame farther up the river." • "Build a dam"

Move floodwater out quickly (sump pumps and drainage systems)	• "A man-made drainage system with a water run-off path would also be helpful to keep the water from contacting places where its not wanted." • "Add drain tile to all the homes to direct water away from the homes…put a larger sump pump in all the homes…put hidden drains in from of businesses so water can drain before it enters the building." • "Use drainage and tileing pipe to help the water flow to somewhere else away from the homes."
Build in better locations	• "Build the house up higher like a hill…Don't build the house by the water." • "Build homes on higher ground and if they can't be built higher just put a levi or a wall/dam that would have water going around the homes, businesses, etc." • "Don't live by water"

Although many female and male students suggested a lack of containment structures including dams, dikes, levees and floodwalls and buildings built too low or close to the river as problems in this scenario differences also existed. Many males discussed temporary solutions to the flooding issue such as sandbags and portable floodwalls the solutions proposed by females tended to be more permanent. Another problem category unique to females was the underutilization of excess water. Females, much more so than males, were interested in finding ways to put the excess water to work such as in irrigating fields during dry spells, filtering and storing in underground aquifers or for providing an alternative energy source. On the other hand males were much more likely to discuss drainage and wetlands problems. Example responses by gender can be seen in Table 17 and Table 18.

Table 17.

Scenario 2 Example Student Responses from Females by Theme

Theme	Example Responses
Find other beneficial uses for the extra water	• "Since the farmers further from the river could use water, streams could be made coming off the river to bring water to the farms and lessen the water in the river. This would be the first choice if possible." • "Build an artificial river (canal directing the flooding to specific points where the water could be used efficiently like farming areas)."
Build on higher ground or raise buildings	• "When building new buildings, build them a safe distance away from the river." • "I would suggest moving homes and businesses to higher ground so as not to be damages by any flooding that may occur, if homes cannot be moved I would make the banks of the river higher so that less flooding would occur."
Dams, dikes and levies	• "Since there must be a long-term solution for the potential flooding of this river, simply adding sandbags would not be optimal…There is a spot about 10 miles upstream that would be a prime spot to build a dam. There was a beaver dam up until a few years ago here, but it has since been destroyed and the beavers have left, which I believe is the reason that there is now an issue with flooding that was no there before." • "Build dams to block water when its overflowing."

Table 18.

Scenario 2 Example Student Responses from Males by Theme

Theme	Example Responses
Temporary solutions (sandbags/portable floodwalls)	• "The first way I would fix it is by putting sand bags along the river to keep it from going over." • "I would build the banks up on the river so it would be harder for it to flood the homes, businesses and farms. Before that I would some water pumps to pump the water. Once the water was gone I would clean the dirt up."
Dams, dikes and levies	• "One this that could be done is the construction of levies along the river bank. These will prevent flood

	levels from reaching buildings or farms."
	• "A small dam with a reservoir upstream of the town would help in that the flow of water would be regulated and could be controlled. However, dams can cause problems with the natural ecosystems, so this problem would have to be addressed according to the location of the dam."
Drainage systems and rerouting	• "Excavate a channel from below the town & reconnect it to the river downstream. The channel would be lined with concrete so it wouldn't erode. The channel will get lower as it approaches the river so water will drain toward the connection down stream."
	• "Put wide, vertical pipes in the ground surrounding the river. Have the pipes go a good distance into the ground, and have many small pipes branching off the main pipe going deeper into the ground (like the roots of a tree). This would allow the water to be absorbed deeper in the ground which would allow for more water to be absorbed, faster, which would lessen the effects of flooding, while keeping the soil moist to prevent any droughts or other problems due to lack of water."
Upstream fixes (i.e. wetlands)	• "Plant a lot of plants that will hold off some water as it floods. They would prevent soil erosion increasing safety from water."
	• "Plant trees along the river to take in more water"

A multivariate analysis of variance showed no statistically significant differences in the four traits of creativity measured by the judges at the .05 alpha level for school, gender or a school/gender interaction. In addition to the MANOVA procedure the data was analyzed using multiple regression to explore differences in each of the four traits based on gender as well as the number of engineering, advanced science and traditional technology education classes reported by each student. The results of these multiple regression analyses for each of the four traits with significant coefficients at the alpha level of .05 are presented in Table 20, Table 21, Table 22 and

Table 23. The multiple regression analysis for originality was not significant at the .05 level. The average judge scores on measures of creativity by school and gender are presented in Table 19.

Table 19.

Scenario 2 Average Scores

	Flexibility	Fluency	Originality	Elaborateness
School 1	2.333	2.381	2.463	2.219
School 2	1.970	2.010	2.103	1.313
School 3	1.944	2.083	2.344	2.022
All Males	1.996	2.063	2.201	1.749
All Females	2.222	2.356	2.686	2.130

Table 20.

Scenario 2 Fluency

	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	SE B	β	
Constant	1.328	.243		.000
Gender	0.155	.340	.051	.649
Engineering Classes	0.298	.172	.187	.086

Advanced Science Classes	0.244	.084	.384	.005
Technology Education Classes	0.332	.139	.312	.019

Note. R^2= .151

Table 21.

Scenario 2 Flexibility

	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	SE B	β	
Constant	1.396	.218		.000
Gender	0.110	.304	.041	.718
Engineering Classes	0.294	.154	.208	.059
Advanced Science Classes	0.200	.076	.354	.010
Technology Education Classes	0.250	.125	.264	.048

Note. R^2= .136

Table 22.

Scenario 2 Originality

	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	SE B	β	
Constant	1.830	.191		.000
Gender	0.285	.268	.119	.290
Engineering Classes	0.186	.135	.150	.173
Advanced Science Classes	0.168	.066	.339	.013
Technology Education Classes	0.104	.110	.126	.345

Note. R^2= .126

Table 23.

Scenario 2 Elaborateness

	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	SE B	β	
Constant	1.739	.221		.000
Gender	0.098	.309	.035	.752
Engineering Classes	0.338	.156	.235	.033
Advanced Science Classes	0.094	.077	.163	.226
Technology Education Classes	-0.230	.127	-.239	.073

Note. R^2= .135

Summary of results

Several interesting observations can be made about the nature and creativity of problems identified in these two scenarios by students at the three participating high schools. First, differences are much more obvious in the qualitative examination of the data than in the quantitative measures of creativity. In fact, the most consistent predictor of creative measures across both scenarios was the number of advanced science classes taken by a student.

Secondly, the qualitative analysis of response categories shows some striking differences in the responses of students, particularly in the first scenario which had an overall greater number of response categories identified. The types of problems identified by school 1 (with engineering courses) and school 3 (with advanced science courses) were much more similar than the types of problems identified by students from school 2 (with traditional technology education courses). In addition, the categories and responses from school 1 and 2 took a much broader approach to the problem, that of an outside engineer, where just about anything was on the table from a complete review of the home design to advanced power saving technology and alternative energy schemes. In contrast the responses from school 2 took a much narrower view of engineering, frequently choosing to look at simple changes a homeowner could make themselves such as replacing light bulbs, appliances and windows. Overall it looks as if there are indeed differences in student responses by school, gender and coursework though these differences manifest themselves in different ways.

Chapter V

Summary and Discussion

Summary

The primary purpose of this study was to examine the state of engineering problem finding ability in high school students at three Minnesota high schools. This goal was undertaken through an examination of the state of engineering problem finding amongst students and schools with a variety of backgrounds and a search for differences between groups of students. The investigation of differences took two distinct paths which both relied on the same set of student responses to two engineering scenarios. The first path explored the differences in problem finding ability through the use of statistical analyses of creativity measures scored by a panel of judges. The second path took a more qualitative approach exploring the different problem categories and ideas generated by students in different groups. Students were presented with two different scenarios which might be faced by an engineer and asked to generate as many problems as possible which, if solved, would improve the situation. Students were asked to be as clear and thorough as possible and to apply their knowledge and skills to generating problems.

As has been described in the preceding chapter there were, indeed, differences found amongst the various student responses. The key differences which were identified are summarized below using the guiding research questions as a framework for discussion of the results.

Differences by school

Although the MANOVA procedure identified no statistically significant differences in the measures of creativity by school a qualitative analysis of categories in student responses did indicate some differences. Specifically, students from School 2 tended to think about things on a smaller scale while students at School 1 and School 3 tended to look at the big picture. For example, within the energy efficiency scenario this manifested itself as things that an individual homeowner could do to improve efficiency versus major changes in the design and construction of homes which were more likely to come from students in School 1 and School 3.

In addition, students from School 2 tended to write shorter and less thorough descriptions of the problems they identified than students in the other two schools. They were also more likely to identify no problems at all or explicitly write that they couldn't think of anything. An informal discussion of the data with one of the judges who had just completed the scoring of the data indicated similar observations.

> School 2 had different responses. They were usually shorter. At first I thought that they were just not given as much time as the other students, but as I kept working I believe they were really trying, but just didn't have the knowledge to talk intelligently on the subjects. That doesn't go for all of them. Many had good things to say. But many of them just wrote a sentence or two or simply said they couldn't think of anything to write down… There was definitely a general lack of a problem solving mentality amongst many of the school 2 students. Granted, there were several with excellent ideas, but these did not occur as often as the other schools.

Another interesting observation was that although students were not prompted in any way to make drawings or sketches some of the students from both School 1 and School 3 did so anyway. None of the students from School 2 made any sketches or drawings.

Differences by gender

Again, the MANOVA procedure identified no statistically significant differences on measures of creativity by gender. There were two instances in the multiple regression analysis of the first scenario where gender was identified as statistically significant, but these are suspect as well because of the very small number of female students. There were some differences evident in the qualitative data. Specifically, in the first scenario the females were more likely to mention changing the design or layout of the house and to suggest that appliances, electronics and lights left on were significant contributors to inefficiency. In the flooding scenario the females mentioned only problems solved by permanent solutions such as dams and diversion systems as well as showing a significant interest in finding ways to take advantage of the extra water.

Overall the differences by gender were not as pronounced as might be expected. This may have been confounded by the much smaller number of female students and the much stronger science background of the females. Still, hints of differences did seem to exist. This was more evident in the types and nature of problems identified than in the creativity of them.

Differences by coursework

Because coursework was a continuous rather than categorical variable it could not be evaluated qualitatively in the way that gender and school were. Instead, coursework in engineering, advanced science, and technology education classes was used in a multiple regression analysis to discern any differences. This was an area where differences were clearly evident.

In both scenarios students with more advanced science classes scored higher on measures of both flexibility and fluency. Interestingly, the fluency scores were also significantly influenced by both engineering (in the first scenario) and technology education (in the second scenario). The engineering and technology education classes seemed to have a larger effect, measured by coefficient size, than the advanced science classes but they were not always significant. None of the classes was significant for measures of originality in both scenarios though there was a slight effect of advanced science classes on originality in the second scenario. Finally, in both scenarios students with more engineering classes scored higher on elaborateness. One additional interesting observation was that technology education students had a statistically significant *decrease* in elaborateness scores for the first scenario.

Discussion

Based on the results of this investigation it is clear that engineering problem finding is not a simple task, nor is it one with which most students are comfortable. Despite directions for both scenarios clearly indicating that the task was to find engineering *problems* and the title of the instrument being an Engineering *Problem Finding* test almost all of the students responded with engineering *solutions*. This was not the case universally but, even among students who gave problems, something compelled most of them to also give solutions to those problems. One potential explanation of this might be the de-emphasis of finding problems within some models of problem solving.

While this study is unique among high school programs there are signs of interest in researching in this vein among collegiate engineering education researchers. A study published by Atman, Yasuhara, Adams, Barker, Turns and Rhone (2008) as this dissertation was under development explored the breadth of problem scoping for both freshman and senior engineering students. Much as this study indicated some differences in the problem finding of students from different school and coursework backgrounds the Atman, et al. study found differences between freshman and senior engineering students.

One of the areas where results seem to align is in the substantialness of student responses. Atman, et al. (2008) noted that seniors gave significantly more substantial responses to their scenario than freshman. One hypothesis for explaining this discrepancy would be that seniors have both more foundational knowledge and a better understanding of the engineering design process than freshman. Looking at the data from this study it was clear that the responses from schools 1 and 3 were frequently more substantial than the responses from school 2. In fact, judges noted this in their comments. Remember that students in school 1 all had some engineering coursework and students in school 3 rigorous physics coursework while students in school 2 were from traditional technology education classes. Given the results of the Atman, et al. (2008) study this would seem to indicate that the substantialness of the student response would be greater among students more familiar or experienced with engineering principles.

In addition to noting differences in how generally substantial the responses were Atman, et al. (2008) also noted that most seniors discussed a wider variety of factors than their freshmen counterparts. Similarly, the students from schools 1 and 3 with more engineering and science background tended to look at a wider variety of problems than students with a technology education background from school 2.

Another issue which came up was that several students either flat out stated they had no ideas or left their response sheets entirely blank for one or both of the scenarios. A hint about why this might be was found on several other student responses where students had specifically written that they found the scenarios “too vague”. This anecdotally confirms the concerns of engineering researchers such as Jonassen, Strobel, & Lee (2006) and Richard Felder (1987) who are concerned that engineering students, schools and classes are too frequently working with well-structured problems. This is problematic when engineers reach the real world and are faced with ill-defined situations.

This inability to deal with ill-structured problems is a potential concern for engineering educators as researchers such as Atman, et al. (2008) have specifically noted the importance of engineers’ ability to define problems in addition to solving them and a tolerance for ambiguity. It further contrasts with the work of Dorst & Cross (2001) where the most creative engineers, a desirable trait in their study, were those who challenged the bounds of the problem and looked at bigger picture problems and solutions. Dorst & Cross (2001) specifically suggest that creative engineers like to “manipulate assignments, because they are often too narrow” (p. 432). If these are the goals and desired traits of engineers there seems to be some work left to be done at the high school engineering level where students remain frustrated, rather than motivated, by ill-structured problems.

As far as differences among the schools, genders and coursework histories go, it is clear that there are some differences. This is especially true in the most common types of problems identified by the various schools and genders and somewhat less so for the four measures of creativity. Of particular note was that students exposed to engineering and advanced science courses were more likely to look at the big picture and think though the scenario as a consulting engineer might while students exposed to a traditional technology education environment were more likely to discuss things on smaller scale.

Limitations

Some care must be taken when interpreting the findings of this study. First, this study was limited by the schools and students which were available for participation. There are many other factors which might have come into play and which could not be controlled as neither the schools nor students were randomly selected. This means that the findings here cannot be generalized to larger populations but should instead be indicators of areas for future research and interest. Second, it is important to understand the overarching goal of this study was to examine and describe the state of engineering problem finding in high school students. Its purpose was not to suggest, imply or determine whether one curriculum or style of education led to superior problem finding skills. The primary purpose was to provide descriptive evidence to aid in the development and interest of future research in the area of engineering problem finding.

Implications and Recommendations

The appropriate definition of a problem can mean the difference between success and failure of a project or a career. If students are to be successful they must develop a firm grasp on the ability to discern problems worth solving. While some students tested in this study were able to identify problems in each of the two scenarios neither the quantity nor scope of problems identified was particularly impressive. The unfamiliarity with finding problems in ill-structured scenarios should be an important wake up call to educators at large and particularly to the engineering education community. Engineering and design is more than drawing up plans for something, it is also determining what to draw plans for in the first place. The understanding of this, which is now becoming clear in collegiate engineering education literature, is still far from adequate among the newer field of high school engineering education.

Perhaps then, one of the most significant contributions of this study is the identification of the continued difficulty that students have in dealing with ill-defined problems. If students, regardless of whether they are bound to be engineers, are to be successful in the real world they must learn to deal with situations which do not have a single correct answer and which cannot simply be solved through the application of technical or mathematical skill. This situation itself is not one which should be difficult to address. Indeed, several students showed much promise in the realm of engineering problem finding so the skill can exist among high school students. Still, the large majority of high school students seem to need significant assistance in developing the critical skills of dealing with open-ended, ill-defined problems and engineering problem finding. Perhaps the issue is one of awareness about the importance of problem finding ability among high school educators and the requisite pedagogical content knowledge to teach this skill.

Additional emphasis on problem finding in engineering could and should be included in technology and engineering instructor professional development as well as collegiate coursework. As teachers become more familiar themselves with the role and work of engineers and develop methods for teaching real-world engineering skills there should be some improvement in the abilities of their students to find engineering problems.

It is hopeful that this study spawns additional interest and research on the ability to teach technological problem finding and problem solving though engineering. Although we understand problem finding and problem solving to be critical aspects of engineering and design we are still in the infancy of understanding the best methods for teaching these skills, especially at the high school level. Beyond teaching, we must also be able to assess the technological or engineering problem finding ability of students for both formative and summative purposes. Atman, et al. (2008) also suggests that looking at problem scoping might be a tool for assessing and improving design education at the collegiate level.

One of the many areas of future inquiry suggested by this study is the question of why differences exist. What in the curriculums of school 1 and school 3 might have made students respond differently than the students in school 2, both in terms of the types and creativity of problems identified? If we determine that the ability to find engineering problems, creative engineering problems, within a scenario is a desirable trait how can this be taught and integrated effectively into the variety of engineering and technology education programs?

While this study focused on the development of creative problems by high school students exposed to an engineering scenario it would be useful to know something about how those problems develop into designs and finally actual solutions. Clearly, the development of solutions is closely tied to the development of problems. Within this study that is evidenced by the great number of students compelled to list not only the problems they identified but what they would propose to do about them. While the development of engineering designs has been the study of collegiate engineering education researchers it has not really been looked at for the high school level despite the increasing level of interest in high school engineering programs. We now know that some differences exist in the problems identified by high school students given an engineering scenario but a logical next step would be to see how these problems become designs and then solutions.

Of course, one key concern for technology and engineering educators is ensuring that students are, and stay, interested in their programs. This is especially a concern at the high school level where many elective courses compete for students. A potential avenue for this suggest by Atman, et al. (2008) is making sure recruitment materials and introductory courses make clear the global and social concerns of engineering rather than focusing too narrowly on technical engineering concepts and problems. As evidenced by the results of this study engineering scenarios can generate a wide variety of problems which are not all of a technical nature.

If engineering hopes to have an enduring place in our high school curriculum it must provide an advantage for all students who take the classes, regardless of whether they go on to be engineers. Engineering, by its very nature, is reliant on problem finding and problem solving skills. Thus, it is in a unique place to teach students these skills, which are continually discussed as critical for all students, in an authentic environment which promotes the transfer of learning.

References

Allender, J. (1969). A study of inquiry activity in elementary school children. *American Educational Research Journal, 6*, 543-558.

Atkinson, S. (1990). Design and technology in the united kingdom. *Journal of Technology Education, 2*(1), 1-12.

Atman, C., Chimka, J., Bursic, K., & Nachtmann, H. (1999). A comparison of freshman and senior engineering design processes. *Design Studies, 20*(2), 131-152.

Atman, C., Yasuhara, K., Adams, R., Barker, T., Turns, J., Rhone, E. (2008). Breadth in problem scoping: A comparison of freshman and senior engineering students. *International Journal of Engineering Education, 24*(2), 234-245.

Bensen, M. J., & Bensen, T. (1993). Gaining support for the study of technology. *The Technology Teacher, 52*(6), 3-5.

Blicblau, A., & Steiner, J. (1998). Fostering creativity through engineering projects. *European Journal of Engineering Education, 23*(1), 55-65.

Brown, S., & Walter, M. (1990). *The art of problem posing* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Burkhart, R. (1967). The relation of intelligence to art ability. In R. Mooney, & T. Razik (Eds.), *Explorations in creativity* (pp. 246-258). New York: Harper & Row.

Chand, I., & Runco, M. (1993). Problem finding skills as components in the creative process. *Personality and Individual Differences, 14*(1), 155-162.

Cotton, S. (2002). Making problem-solving simulations more realistic. *The Technology Teacher, 62*(3), 29-32.

Cross, N. (1999). Natural intelligence in design. *Design Studies, 20*(1), 25-39.

Csikszentmihalyi, M. (1994). The domain of creativity. In D. Feldman, M. Csikszentmihalyi & H. Gardner (Eds.), *Changing the world: A framework for the study of creativity* (pp. 135-158). Westport, CT: Praeger.

Dewey, J. (1910). *How we think*. Boston: Heath.

Dori, Y., & Herscovitz, O. (1999). Question-posing capability as an alternative evaluation method: Analysis of an environmental case study. *Journal of Research in Science Teaching, 36*(4), 411-430.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies, 22*(5), 425-437.

Duncker, K. (1945). In John F. Dashiell (Ed.), *On problem solving*. Washington, DC: American Psychological Association.

Einstein, A., & Infeld, L. (1961). *The evolution of physics*. New York: Simon and Schuster.

English, L. (1998). Children's problem posing within formal and informal contexts. *Journal for Reserach in Mathematics Education, 29*(1), 83-106.

Felder, R. (1987). On creating creative engineers. *Engineering Education*, *77*(4), 222-227.

Garmire, E. (2003). The engineering design method. *The Technology Teacher*, *62*(4), 22-28.

Getzels, J. (1964). Creative thinking, problem solving, and instruction. In Ernest R. Hilgard (Ed.), *Theories of learning and instruction: The sixty-third yearbook of the national society for the study of education* (pp. 240). Chicago: University of Chicago Press.

Getzels, J. (1979). Problem finding: A theoretical note. *Cognitive Science*, *3*, 167-172.

Getzels, J. (1982). The problem of the problem. In R. Hogarth (Ed.), *Question framing and response consistency* (pp. 37). San Francisco: Jossey-Bass.

Getzels, J., & Csikszentmihalyi, M. (1976). *The creative vision: A longitudinal study of problem finding in art*. New York: John Wiley & Sons.

Goldman, R. (1967). The Minnesota tests of creative thinking. In R. Mooney, & T. Razik (Eds.), *Explorations in creativity* (pp. 267-280). New York: Harper & Row.

Gradwell, J. B. (1996). Philosophical and practical differences in the approaches taken to technology education in England, France and the United States. *International Journal of Technology and Design Education, 6*(3), 239-262.

Guilford, J. (1950). Creativity. *American Psychologist, 5*(9), 444-454.

Guilford, J. (1959). Intellectual resources and their values as seen by scientists. In C. Taylor (Ed.), *The third university of Utah research conference on the identification of creative scientific talent* (pp. 128-149). Salt Lake City: University of Utah Press.

Guilford, J. (1967). Measurement of creativity. In R. Mooney, & T. Razik (Eds.), *Explorations in creativity* (pp. 281-287). New York: Harper & Row.

Hill, A., & Smith, H. (1998). Practice meets theory in technology education: A case of authentic learning in the high school setting. *Journal of Technology Education, 9*(2), 29-45.

Hitt, W., & Stock, J. (1967). The relation between psychological characteristics and creative behavior. In R. Mooney, & T. Razik (Eds.), *Explorations in creativity* (pp. 259-266). New York: Harper & Row.

Hoover, S. (1994). Scientific problem finding in gifted fifth-grade students. *Roeper Review, 16*(3), 156-159.

Hoover, S., & Feldhusen, J. (1990). The scientific hypothesis formulation ability of gifted ninth-grade students. *Journal of Educational Psychology, 82*(4), 838-848.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: International Technology Education Association.

Johnson, S. (1992). A framework for technology education curricula which emphasizes intellectual processes. *Journal of Technology Education, 3*(2), 26-36.

Jonassen, D. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research and Development, 45*(1), 65-94.

Jonassen, D. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85.

Jonassen, D., Strobel, J., & Lee, C. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139-151.

Lee, H., & Cho, Y. (2007). Factors affecting problem finding depending on degree of structure of problem situation. *The Journal of Educational Research, 101*(2), 113-124.

Lewis, T. (2005a). Coming to terms with engineering design as content. *Journal of Technology Education, 16*(2), 37-54.

Lewis, T. (2005b). Creativity - A framework for the Design/Problem solving discourse in technology education. *Journal of Technology Education, 17*(1), 35-52.

Lewis, T., Petrina, S., & Hill, A. (1998). Problem posing: Adding a creative increment to technological problem solving. *Journal of Industrial Teacher Education, 36*(1) Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v36n1/lewis.html

Lumsdaine, E., & Lumsdaine, M. (1994). Creative problem solving. *IEEE Potentials, 13*(5), 4-9.

Mathews, B., & Bailey, R. (1965). A course in creative problem solving. *IEEE Transactions on Education, 8*(4), 85-90.

McPherson, J. (1964). Environment and training for creativity. In C. Taylor (Ed.), *Creativity: Progress and potential* (pp. 130-153). New York: McGraw-Hill.

Merriam-webster's online dictionary. (2008). Retrieved June, 24, 2008, from http://www.merriam-webster.com/

Middleton, H. (2005). Creative thinking, values and design and technology education. *International Journal of Technology and Design Education, 15*, 61-71.

Mooney, R., & Razik, T. (1967). Creativity: Measurements. In R. Mooney, & T. Razik (Eds.), *Explorations in creativity* (pp. 217-218). New York: Harper & Row.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: National Council of Teachers of Mathematics.

National Council of Teachers of Mathematics. (1991). *Professional standards for teaching mathematics*. Reston, VA: National Council of Teachers of Mathematics.

Newell, A., & Simon, H. (1972). *Human problem solving*. Englewood Cliffs, New Jersey: Prentice Hall.

Okuda, S., Runco, M., & Berger, D. (1991). Creativity and the finding and solving of real-world problems. *Journal of Psychoeducational Assessment, 9*, 45-53.

Oxford English Dictionary (2008). Oxford University Press. Retrieved from http://dictionary.oed.com

Pappas, E. (2002). Creative problem solving in engineering design. *Proceedings (Juried) of the American Society of Engineering Education (ASEE) Southeastern Section Meeting*, University of Florida, Gainsville.

Pearson, G., & Young, A. (2002). *Technically speaking: Why all Americans need to know about technology*. Washington, DC: National Academies Press.

Perkins, D. (1990). The nature and nurture of creativity. In B. Jones, & L. Idol (Eds.), *Dimensions of thinking and cognitive instruction* (pp. 415-443). Hillsdale, NJ: Lawrence Erlbaum Associates.

Polya, G. (1957). *How to solve it*. Princeton, NJ: Princeton.

Roman, H. (2001). Technology education - process or content? *The Technology Teacher*, *60*(6), 31-33.

Shodell, M. (1995). The question-driven classroom: Student questions as course curriculum on biology. *The American Biology Teacher*, *57*, 278-281.

Silver, E., & Cai, J. (1996). An analysis of arithmetic problem posing by middle school students. *Journal for Research in Mathematics Education*, *27*(5), 521-539.

Silver, E., Mamona-Downs, J., Leung, S., & Kenney, P. (1996). Posing mathematical problems: An exploratory study. *Journal for Research in Mathematics Education, 27*(3), 293-309.

Smilansky, J. (1984). Problem solving and the quality of invention: An empirical investigation. *Journal of Educational Psychology*, *76*(3), 377-386.

Taylor, C., & Holland, J. (1967). Development and application of tests of creativity. In R. Mooney, & T. Razik (Eds.), *Explorations in creativity* (pp. 219-228). New York: Harper & Row.

The National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform*. Washington, DC: U.S. Government Printing Office.

The Secretary's Commission on Achieving Necessary Skills. (1991). *What work requires of schools: A SCANS report for america 2000*. Washington, DC: U.S. Department of Labor.

Torrance, E. (1966). *Torrance tests of creative thinking: Norms-technical manual*. Princeton, NJ: Personal Press.

Tracy, P. (2005). *Design and problem-finding in high schools: A study of students and their teacher in one Queensland school.* Unpublished Master of Philosophy, Griffith University, Queensland, Australia.

U.S. Department of Labor. (2007). *Occupational outlook handbook.* Retrieved June 20, 2008, from http://www.bls.gov/oco/ocos027.htm

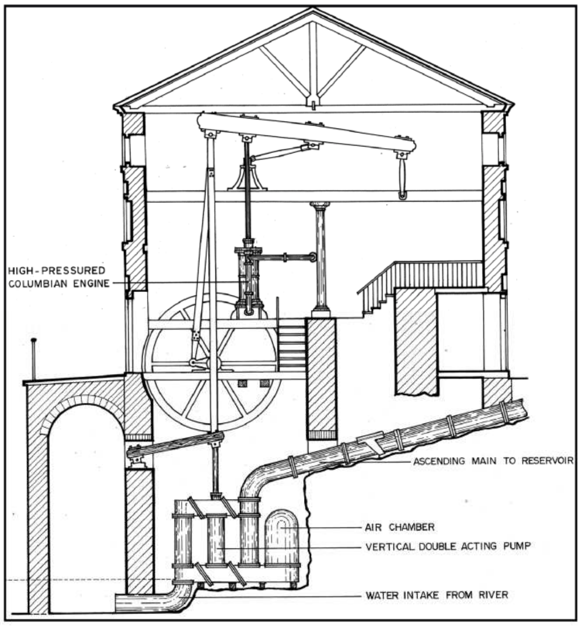
Weisberg, R. (1988). Problem solving and creativity. In R. Sternberg (Ed.), *The nature of creativity: Contemporary psychological perspectives* (pp. 148-176). New York: Cambridge University Press.

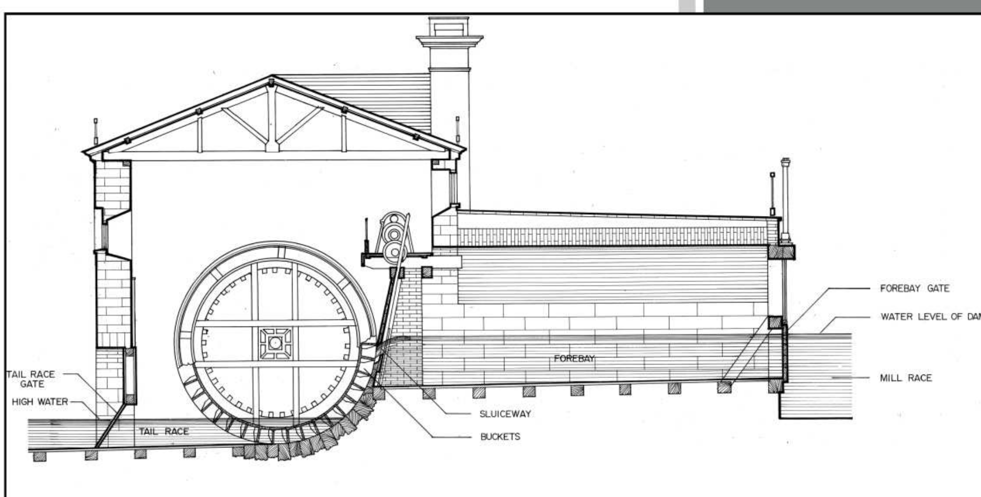
Wicklein, R. (2006). 5 good reasons for engineering design as THE focus for technology education. *The Technology Teacher*, *65*(7), 25-29.

Appendix A

Instrument

Engineering Problem Finding





Version 1.5

This test of problem finding ability is part of a research study being conducted by a researcher at the University of Minnesota studying the problem finding ability of high school students. You should already have been provided with an informational sheet detailing this study. It is important to note that it is up to you to decide to participate in this anonymous study and there is no penalty for failing to participate but in the interest of fairness all students will be asked to complete this exercise in problem finding. Should you choose not to participate in the study your paper will not by looked at further by the researcher. Please indicate that you have been informed of the purpose and nature of this study by checking the appropriate line below.

☐ YES, I agree to participate in this research study and have received sufficient information about the purpose and nature of the study.

☐ NO, Please do not use my answers as part of this research

Demographic Information

Please indicate whether you are a ☐ MALE or ☐ FEMALE

Please list the names of any industrial technology, technology education, engineering or AP or enriched science courses you have taken in the past as well as what grade you were in at the time:

Course Name	Grade

The following pages contain two scenarios which might be encountered by an engineer. Please read through each scenario and think of how you would go about improving each situation. You should roughly divide the remaining time in half and spend about half the time working on each scenario. You may use the remaining pages to respond to the scenario. If you use any of your own paper please turn that in with the test booklet.

Scenario 1:
You have been hired as a consulting engineer for a residential architectural and construction firm which is concerned that the houses it is designing are not as energy efficient as possible. With the recent rise in energy costs they are concerned that high energy use will discourage potential home buyers.

Guidelines:
1) Find original and novel problems which if solved would increase the energy efficiency of homes
2) Write down *and describe* the problems you would solve in a way that other people can understand them as clearly as possible
3) Apply your knowledge as much as possible

Scenario 2:
You have been hired as a consulting engineer by a government organization which is concerned about flooding along a local river and it’s impact on homes, businesses, and farms.

Guidelines:
1) Find original and novel problems which if solved would improve the flooding situation
2) Write down *and describe* the problems you would solve in a way that other people can understand them as clearly as possible
3) Apply your knowledge as much as possible

Appendix B

Parental Consent Letter and Consent Information Sheet

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Business and Industry Education
Department of Work and Human Resource Education
College of Education and Human Development

1954 Buford Avenue, Room 425
St Paul, MN 55108-6197
Office: 612-624-3004
Fax: 612-624-4720
www.cehd.umn.edu/whre

December 3, 2008

Dear Parents and Guardians:

Your child is invited to participate in a research study conducted by Benjamin Franske, from the University of Minnesota Department of Work and Human Resource Education. As part of my Ph.D. dissertation I hope to learn more about how students find engineering problems. Your child's school and teacher have agreed to participate in this study and your child's class was selected because of a focus on engineering.

To be fair all students in your child's class will be asked to complete an anonymous written problem finding test. This test will take about 55 minutes during their regular class period. The test will consist of a short demographic section and two scenarios which your child will be asked to evaluate for engineering problems. Although all students will complete the test only tests from students who have agreed to participate in the research study will be returned to me. *If you* ***do not*** *wish to have your student's test used in this research study you may either sign and return the form at the bottom of this letter or ask your child to check the box on the test indicating that they do not wish for it to be used for research purposes.*

Participation in this research is voluntary, anonymous and involves no risks beyond those normally encountered in the school environment. This test will not be graded or scored by your child's teacher and *will not affect their grade in any way regardless of participation*. The primary benefit of participation for your child is additional practice in technological and critical thinking skills. Additionally, it is expected that this research will improve our understanding of technology and engineering education. However, I cannot guarantee that you or your child will personally receive any benefits from this research.

Your child's participation in this research is entirely voluntary. Your decision whether or not to let your child participate will not affect your relationship with their teacher, school or the University of Minnesota. If you decide to allow your child to participate, you are free to withdraw your consent and discontinue your child's participation at any time without penalty.

In accordance with federal law this research project and copies of the problem finding test are reviewed by the University of Minnesota Institutional Review Board prior to test administration. In addition, your child's teacher will have extra copies of the test which students may bring home after the test is given if you are interested in a copy. Finally, if you are interested in the final report of this research it will be available from your school principal or directly from the researcher once the project is completed.

If you have any questions about the study or your child's participation please feel free to contact me via email at frans046@umn.edu or by phone at 952-200-8945. You are also welcome to contact my advisor Dr. Theodore Lewis at 612-624-4707 or via email at lewis007@umn.edu. If you have questions regarding your child's rights as a research subject or wish to speak with someone other than the researcher, contact the University of Minnesota Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650. This Office oversees the review of the research to protect your rights and is not involved with this study.

Sincerely,

Ben Franske

Ben Franske
Researcher

If you <u>do not</u> give your consent for your child's participation in this study of problem finding, please sign the bottom portion of this form and return it to your child's teacher by December 10 or ask your child to indicate that their test should not be used for research on the test itself.

I DO NOT give consent for my child (name)_________________________ to participate in this study

Print Parent/Legal Guardian name: ________________________________

Parent/Legal Guardian Signature:________________________________ Date_______________________

UNIVERSITY OF MINNESOTA
STUDY INFORMATION SHEET

An analysis of high school engineering problem finding ability

You are invited to participate in a research study about engineering problem finding ability in high school students. You were selected as a possible participant because your school and teacher have agreed to participate. You should already have received a letter to your parents detailing your potential participation in this voluntary and anonymous study. It is up to you and your parents to decide if your anonymous answers will be used as part of this research but in the interest of fairness all students in your class will be completing the in-class test.

This study is being conducted by: Benjamin Franske from the Work & Human Resource Education department at the University of Minnesota.

Background Information

The purpose of this study is to examine the ability of high school students to find and define engineering problems in real world scenarios. I am interested primarily in describing what types of problems high school students find when presented with an engineering challenge and in looking at how engineering, science and technology classes prepare you for these challenges.

What you will be asked to do:

All students in your class will be taking a problem finding test which will take about 55 minutes to complete. It will include some background demographic questions in addition to two scenarios. If you agree to be in this study your test booklet will be forwarded on to the researcher, if you decline to participate in the study your test booklet will be destroyed and not seen by the researcher. The study is voluntary and anonymous; at no time will you be asked to provide identifying information.

Risks and Benefits of being in the Study

Participating in this study has no known risks other than those normally encountered in school.

The benefits to participation are: Additional practice in technological and critical thinking skills. Additionally, it is expected that this research will improve our understanding of technology and engineering education. However, I cannot guarantee that you will personally receive any benefits from this research.

Confidentiality:

This study will be conducted anonymously; at no time will you be asked to provide identifying information. Responses from your test booklet may be used or published in the final report but will not be linked to you.

Voluntary Nature of the Study:

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with your school, teacher or the University of Minnesota. There is no penalty for choosing not to participate or withdrawing from the study at any time, it will not affect your grades, graduation or college admittance in any way.

Review of the Study:

This study has been reviewed and approved by the University of Minnesota Institutional Review Board (IRB). The IRB has determined that this study meets the ethical obligations required by federal law and University policies. If you have questions or concerns regarding this study please contact the Investigator or Advisor. If you have any questions, concerns, or reports regarding your rights as a research subject, please contact the IRB Administrator.

Copies of the Test and Study Report:

Following administration of the test additional test booklets will be available for you to take with you for your records. Your original test booklet cannot and will not be returned to you as it contains no identifying information. Copies of the final study report will be available from your school principal or directly from the researcher at the conclusion of the study.

Contacts and Questions:

The researcher conducting this study is: Ben Franske. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact them at the University of Minnesota, 952-200-8945, frans046@umn.edu. Questions may also be directed to the study advisor Dr. Theodore Lewis at the University of Minnesota, lewis007@umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the University of Minnesota Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650.

This sheet is for you to keep for your records.

This project has been reviewed by the University of Minnesota IRB as required by the Code of Federal Regulations Title 45 Part 46

Appendix C

School Recruitment

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Business and Industry Education
Department of Work and Human Resource Education
College of Education and Human Development

1954 Buford Avenue, Room 425
St Paul, MN 55108-6197
Office: 612-624-3004
Fax: 612-624-4720
www.cehd.umn.edu/whre

June 2008

Dear Principal:

My name is Benjamin Franske. I'm currently a Ph.D. student in Technology and Engineering Education at the University of Minnesota. I am conducting a dissertation study on the initial stages of engineering problem solving at the 11th grade level. Students in this study will receive a small set of real world engineering problems and asked what questions they would ask in order to solve the problem as well as essential demographic questions including the nature of any prior courses in science, engineering or technology. I am seeking your permission to conduct this research within your school. No student names or correspondence with individual students will be required and all collected data will be treated confidentially. The study will be approved by the University of Minnesota Institutional Review Board and done in conformity with the research regulations of your district.

Data for this study will be collected in Fall 2008. If your school has technology or engineering courses I would like to conduct the survey in those courses, if not I would like to collect data in a general education course. Data will be collected from schools with varied income levels, rural, suburban and urban schools as well as schools with technology or engineering programs and those without. It is expected that participating students will require about one standard (45-55 minute) class period to complete their part in this study.

The results of this study will be useful for schools and curriculum designers, particularly in the science, technology and engineering fields. Results and a copy of the final report will be available at the conclusion of the study. If you agree to allow me to conduct this research in your school I will need a letter of cooperation. A sample letter is enclosed; please return your letter on school stationary. Please also indicate what, if any, technology education, industrial arts or engineering courses your district has.
Please send this letter to:
Ben Franske
6104 Arbour Ave.
Edina, MN 55436

If you have any questions about the study, your school's participation or the letter of cooperation please feel free to contact me via email at frans046@umn.edu or by phone at 952-200-8945. You are also welcome to contact my advisor Dr. Theodore Lewis at 612-624-4707 or via email at lewis007@umn.edu. I look forward to partnering with you on this important study and thank you for your assistance.

Sincerely,

Ben Franske

Ben Franske
Researcher

Theodore Lewis

Dr. Theodore Lewis
Advisor

Driven to Discover℠

Sample Letter of Cooperation

Must be on school letterhead

<Date>

Ben Franske
6104 Arbour Ave.
Edina, MN 55436

To Whom It May Concern:

Benjamin Franske has requested permission to collect dissertation research data about engineering problem solving from students at <name of school/district>. I have been informed of the purpose of the study as well as the data collection procedures and approximate timeframe. I have also been given an opportunity to ask questions of the researcher and advisor.

I understand that this research will be carried out following ethical research principals and will be approved by the University of Minnesota Institutional Review Board prior to data collection. Individual participant involvement in this study is strictly voluntary and no student names or personally identifiable information will be collected. I understand that parents/guardians and students will be notified in advance about this research and provided an opportunity to decline involvement without penalty if they so choose.

Therefore, as a representative of <name of school/district>, I am authorized to grant permission to have the researcher, Benjamin Franske, to recruit participants and collect data at <name of school/district>.

If you have any questions please contact me at <your contact information>.

Sincerely,

<Name of authorized representative>
<Official title>

Additional Information:
Our <school/district> has the following technology education/industrial technology/engineering courses: <list any courses you have>. Data collection would be most welcome in <list courses which would be available for data collection> which would include roughly <estimated number of students> students.

Appendix D

Judge Scoring Packet

Reviewer #:

Dear Judge,

Thank you for taking the time out of your busy schedule to help with the evaluation and scoring of these engineering problem finding tests. Hopefully you'll find this a fairly straightforward process but if at any time you are confused or unclear please don't hesitate to contact me (frans046@umn.edu or 952-200-8945). Attached you will find several things which should clarify what your task is and how to go about it.

First, I'll include a short background on the study as a whole so you have some idea where this is going and what your responses will be used for. Second, I'll describe what I'm looking for from you and some basic information about the scoring of creativity. Third, will be some specific instructions for the scoring of student responses. Attached will be a sample student response which I have filled out myself to give you some ideas about different directions students might go as well as a rubric to further clarify the scoring and an example real student response which I have scored and given some rationale for how I determined scores in the specific instructions for scoring a scenario.

I really appreciate your willingness to help out with this project and please do not hesitate to let me know if there is anything I can do for you in the future.

Thanks,

Ben Franske
University of Minnesota
Department of Work & Human Resource Education

Study Background

Many of the problems in our modern world which engineers are asked to solve are not well structured. For example, an engineer may be asked to improve the energy efficiency of a building, fix a problem with the water in a remote village or alleviate a traffic problem in a city. Each of these problems has an identifiable goal but none an immediately apparent path to solution. The path chosen by the engineer is, for a large part, determined by their identification of a specific problem to address which they believe will address the larger issue most effectively. This process of need or problem identification is generally accepted to be the first step in the design process. It is obviously a critical step as it sets the tone for the forthcoming solution yet it is often not one that is especially well addressed in engineering courses and curriculum.

Little is currently known about the ability of high school students to find engineering problems or how this ability is related to participation in technology or engineering education courses. Therefore, it is the goal of this study to measure and describe the question posing capabilities of high school students with a variety of backgrounds including those which have taken technology education or engineering courses and those who have not. Students will be presented with two scenarios which might be encountered by a practicing engineer. Question posing skills will be evaluated by a panel of judges comprised of engineers as well as technology educators and experts in creativity on the fluency, flexibility, originality, appropriateness and elaborateness of the questions posed by each student after examining the scenarios. In addition to these scores the panel will also be looking for patterns and categories in student response.

Gauging Creativity

While there are many methods which have been proposed for gauging creativity this study will use the areas of creativity identified by Guilford, namely fluency, flexibility, originality and elaborateness as well as the check of appropriateness to weed out irrelevant responses. Because these will be the primary areas of your assessment a brief description of each term is included below.

The **fluency factor** recognizes that, all other things being equal, those students who generate the most ideas per unit of time are more likely to have ideas of interest and significance than those who generate fewer ideas. Therefore, fluency is primarily concerned with the number of ideas generated by the student.

Flexibility involves the ability of the student to generate ideas which lead to many different branches of investigation rather than staying in a rut. A more flexible student would look at many very different ways of addressing a scenario which they encounter. For example, in the case of needing to cross a river a less flexible student might identify the problem as a lack of a bridge and propose several variations of bridge design while a more flexible student would propose many alternatives such as a water ferry system, a tunnel, diverting the river, a bridge, or an aerial ferry.

Creative students have **novel or original** ideas. Although the responses must be acceptable or appropriate for the scenario the ability to generate uncommon ideas is a valuable measure of creativity. We might also call this the ability to “think outside the box”.

In order to be successful the creative student must also be able to clearly communicate and **elaborate** on their ideas. This elaboration allows for the problem to be redefined and further developed by the student as well as to clarify the relevance to the given situation. Elaboration may take many forms including diagrams and drawings as well as the written word.

Remember that the goal for students was not to “solve” the scenario but to generate potential problems which, if solved, would improve the situation. In many cases the students do identify solutions rather than problems. For the purposes of scoring I would ask you to determine what the underlying potential problem they attempted to solve was. I think as you look at my example of a scored response you’ll see how I did that.

In general, I don’t mind how you go about determining where one problem ends and another begins or when responses should be lumped together but I do ask that you be consistent. I would also encourage you to browse through several of the responses from each school (the school is the first set of numbers in the student ID tags (eg. 01-xx-xx) before you start scoring. This will allow you to get some sense of the variety of responses and problems identified by students which is important for accurately scoring how original ideas are.

Scoring the Scenarios

Note that it may be helpful to look at the example of a scored student response as you read over this. The directions here specifically address my rationale for scoring this example.

1. Copy the student ID to and mark the scenario number and your reviewer number on the evaluation form. The key part of the student ID is the first two pairs of numbers (01-08 in the example) with the third one being a page number. It would also be helpful if you made note of any trends from one school to the next (the first two numbers, in this case 01) to aid in later comparison.
2. Read through the entire student response to the scenario including any additional pages if they used them. As you're reading through decide how many disparate problems the student identified and what they are. Student responses vary from clearly delineated lists to paragraph format to drawings and sketches. It may be helpful to label the problems in the margin of the page as you identify them. This is what I did in the example but this is not required and you will not be returning the student responses to me so mark them up (or not) as you see fit. Not all judges will identify the same problems in student responses but please be as consistent as possible about how you identify when one problem ends and another begins. For example, in my sample evaluation I treated air seepage through cracks as a different problem than poor door/window seals but you may decide to treat these types of responses as one or as three as long as you do so consistently across all students.
3. Once you have read the entire response of the student give the student an overall rating on fluency with assistance from the rubric. In the example I gave a fluency rating of 3 because the number of problems the student identified is about what I expect to be the average number of problems identified. It may be helpful as you're getting started to browse through a few randomly picked responses to get an idea of what to expect. **Fluency deals primarily with the number of problems found.**
4. Do the same for flexibility. My flexibility rating of 3 was because I saw three large categories addressed: radiant heat loss, air leakage, furnace efficiency. The more difference between the categories the higher this rating should be. For example, in the sample of my own responses I listed problems dealing with appliance efficiency, radiant heat loss, air leakage, high fuel costs, the marketing perception of high energy costs, inefficient floorplan, etc. because of the large number of different categories I would receive a very high flexibility rating. **Flexibility deals primarily with the number of broad categories the problems fall into.**
5. Now move into the per problem rating. For each of the problems you identified determine whether it is appropriate to the scenario. I expect it will be rare to encounter an inappropriate problem but **if you feel that a given problem has no relationship at all to the scenario this is the place to indicate so.**
6. Continuing to look at each problem individually give a score for originality. **In general the fewer students who identified the problem the more original it is.** In the example I scored I gave the first problem I identified (lack of roof insulation) an originality score of 2 because based on what I've seen looking through student responses this is a very common one.

7. **In evaluating the elaborateness you are scoring how thoroughly each problem was developed/explained by the student.** In the example I scored I gave the first problem I identified (lack of roof insulation) an elaborateness score of 3 because the student explained why the problem is important and material to the scenario.
8. Finally, give any comments or notes you have about the student's response to this scenario. I'm particularly interested in anything interesting/different the student described. In the example I scored I noted my skepticism about whether electric furnaces were really more efficient, that a major focus was reducing air/heat movement and that alternative fuels (electricity vs. fossil) were mentioned. You are not required to make comments on all evaluations but if you see something interesting, unusual or creative please make a note of it!

SAMPLE

Scenario 1:
You have been hired as a consulting engineer for a residential architectural and construction firm which is concerned that the houses it is designing are not as energy efficient as possible. With the recent rise in energy costs they are concerned that high energy use will discourage potential home buyers.

Guidelines:
1) Find original and novel problems which if solved would increase the energy efficiency of homes
2) Write down *and describe* the problems you would solve in a way that other people can understand them as clearly as possible
3) Apply your knowledge as much as possible

- Improve the radiant heat exchange through increased insulation in exterior walls
- Air leakage allows cold/hot air and humidity to migrate
- The furnace efficiency could be raised reducing fuel costs
- Water pipes + ducts could be insulated to reduce transmission inefficiencies
- Hot water heater could be instant type instead of standby
- Furnace could be supplemented by geothermal or air to air heat exchanger
- Energy Star appliances could replace less efficient ones
- Sprinkler system with timer and rain sensor could replace manual watering during the day which is more prone to evaporation
- Home could be certified by LEED or other group as energy efficient to improve marketability
- Floorplan could be changed to be less open so only rooms in use would be heated/cooled
- Home could be built underground or into hill to take advantage of stable earth temperatures
- Large eaves and window treatments could be used to take advantage of passive solar heating in the winter and reflect it in the summer

SAMPLE

Scenario 2:
You have been hired as a consulting engineer by a government organization which is concerned about flooding along a local river and it's impact on homes, businesses, and farms.

Guidelines:
1) Find original and novel problems which if solved would improve the flooding situation
2) Write down *and describe* the problems you would solve in a way that other people can understand them as clearly as possible
3) Apply your knowledge as much as possible

- Buildings built in floodplain to begin with
  - move buildings out of flood plain
  - restrict building in floodplain
  - elevate buildings above high water expectations
- Existing buildings sustain damage during a flood
  - Protect buildings with sandbags (enough available?)
  - Business district protected by levy/dike system
  - Waterproof building exteriors to keep water out
  - Install large drainage system under streets to carry away water
- River might flood
  - Improve upstream floodplain/ecosystem to absorb more water
  - Build a dam to control river flow
  - Build water diversion channels around town
- Supplies to town might be cutoff
  - reinforce bridges to prevent washouts
  - elevate bridges to keep them open during flooding
- People injured/caught off guard
  - develop early warning system in case of dam failure or ground saturation
  - develop evacuation routes which will remain open during flooding

Engineering Problem Finding Creativity Rubric

	1	3	5
Fluency	The student identified few or no problems in the given scenario which could improve the situation.	The number of problems identified in this scenario by the student is on par with the number expected or identified by other students.	The student identified many problems in the given scenario which could improve the situation.
Flexibility	Problems identified by the student in the given scenario are all very similar. Most or all of the problems identified by the student in this scenario fall into one or two categories.	Problems identified by the student in the given scenario have some variety of approaches. A few different categories of problems are represented in the student's responses.	Problems identified by the student in the given scenario lead to many different approaches. Several categories of problems are represented.
Originality	This particular problem identified by the student is commonly suggested. It is not particularly unique, clever or unusual and may be one of the most obvious problems to solve or investigate.	This problem is somewhat clever, unique or unusual. Some other students may have thought of it or something similar but it is not immediately apparent and could present a different way of looking at things.	This problem is very clever, unique or unusual. Few if any other students thought of it. This problem is not immediately apparent and presents a different but possibly effective method of addressing the scenario.
Elaborateness	There are few details, embellishments or explanations of this problem. A limited amount of time and/or thought seems to have gone into it.	This problem was somewhat developed and explained by the student. Some time and/or thought seems to have gone into it but it could have been further developed or explained.	This problem includes a significant amount of detail or explanation. Considerable time and/or thought appears to have gone into developing it.

	No	Yes
Appropriateness	The problem identified by the student is not material to improving the situation presented in the scenario.	The problem identified by the student could possibly improve the situation presented in the scenario.

SAMPLE

Student ID: 01 - 08 - 01	Scenario: 1 2	Reviewer #: 99

Per Scenario Ratings:

Please rate the flexibility and fluency skills of this student as evidenced *on this scenario as a whole* using the provided rubric as a guideline.

Fluency:	1	2	3	4	5
Flexibility:	1	2	3	4	5

Per Problem Ratings:

Please rate the appropriateness, originality and elaborateness *of each problem the student described* in this scenario using the provided rubric as a guideline. In the event a student has identified more than 12 problems use a supplemental sheet to continue scoring.

Problem	Appropriateness		Originality					Elaborateness				
1	Y	N	1	2	3	4	5	1	2	3	4	5
2	Y	N	1	2	3	4	5	1	2	3	4	5
3	Y	N	1	2	3	4	5	1	2	3	4	5
4	Y	N	1	2	3	4	5	1	2	3	4	5
5	Y	N	1	2	3	4	5	1	2	3	4	5
6	Y	N	1	2	3	4	5	1	2	3	4	5
7	Y	N	1	2	3	4	5	1	2	3	4	5
8	Y	N	1	2	3	4	5	1	2	3	4	5
9	Y	N	1	2	3	4	5	1	2	3	4	5
10	Y	N	1	2	3	4	5	1	2	3	4	5
11	Y	N	1	2	3	4	5	1	2	3	4	5
12	Y	N	1	2	3	4	5	1	2	3	4	5

Comments:
electric furnaces more efficient?
mostly reducing air /heat movement
alternative fuel sources

SAMPLE

Scenario #

Scenario 1:
You have been hired as a consulting engineer for a residential architectural and construction firm which is concerned that the houses it is designing are not as energy efficient as possible. With the recent rise in energy costs they are concerned that high energy use will discourage potential home buyers.

Student ID #

01-08-01

Guidelines:
1) Find original and novel problems which if solved would increase th
2) Write down *and describe* the problems you would solve in a way th
as clearly as possible
3) Apply your knowledge as much as possible

Lack of Insulation on roof

Heat rises, and therefore the first step to energy efficiency is to make sure the roof is well insulated. In order to do this it is as simple as adding more insulation to the ceiling of the top story of the house, and sealing any gaps or cracks that may cause heated air to seep out.

air seepage through cracks

Another possible problem could be that the doors and windows do not seal properly, and let in cold outside air. This problem is also easily solved by installing heavier, thicker doors, and new weather seals that do not let as much air in. Also, the windows of the house should be dual pane and open on a hinge rather than be double-hung, in order to reduce the amount of seals that could possibly leak energy.

Door/Window Seals

The choice of furnaces can also play a part in energy use. An electric furnace may be beneficial because the cost does not rely as much on fossil fuels, like other furnaces. However an electric furnace, though cheaper to operate, does not use energy as efficiently as some gas furnaces. This is something that would need to be looked at more closely to insure the correct choice of furnace.

Furnace Efficiency

Student ID: 01 - 08 - 02	Scenario: 1 2	Reviewer #: 99

Per Scenario Ratings:

Please rate the flexibility and fluency skills of this student as evidenced *on this scenario as a whole* using the provided rubric as a guideline.

Fluency:	1	2	3	4	5
Flexibility:	1	2	3	4	5

Per Problem Ratings:

Please rate the appropriateness, originality and elaborateness *of each problem the student described* in this scenario using the provided rubric as a guideline. In the event a student has identified more than 12 problems use a supplemental sheet to continue scoring.

Problem	**Appropriateness**		**Originality**					**Elaborateness**				
1	Y	N	1	2	3	4	5	1	2	3	4	5
2	Y	N	1	2	3	4	5	1	2	3	4	5
3	Y	N	1	2	3	4	5	1	2	3	4	5
4	Y	N	1	2	3	4	5	1	2	3	4	5
5	Y	N	1	2	3	4	5	1	2	3	4	5
6	Y	N	1	2	3	4	5	1	2	3	4	5
7	Y	N	1	2	3	4	5	1	2	3	4	5
8	Y	N	1	2	3	4	5	1	2	3	4	5
9	Y	N	1	2	3	4	5	1	2	3	4	5
10	Y	N	1	2	3	4	5	1	2	3	4	5
11	Y	N	1	2	3	4	5	1	2	3	4	5
12	Y	N	1	2	3	4	5	1	2	3	4	5

Comments:

suggests some people move — no mention of policy/zoning
(on their own)

mentions ecosystem damage

" economic effects

Scenario 2:
You have been hired as a consulting engineer by a government organization which is concerned about flooding along a local river and it's impact on homes, businesses, and farms.

Guidelines:
1) Find original and novel problems which if solved would improve th
2) Write down *and describe* the problems you would solve in a way th
as clearly as possible
3) Apply your knowledge as much as possible

01-08-02

Lack of Insurance

First of all, if the ~~th~~reat of flooding is serious, everyone that could possibly be affected should buy Flood insurance. It is just plain stupid to live in a potential flood zone without this. If people cannot afford insurance they should move to a location free from this danger of flooding.

People living too close

A small dam with a resevoir upstream of the town would help in that the flow of water would be regulated and could be controlled. However, dams can cause problems with the natural ecosystems, so this problem would have to be adressed according to the location of the dam. Having a dam and resevoir would probably be the best and most economical solution to the problem of flooding. Since dams have been widely used for the past centuries, we are experts at building them and in a way that the ecosystems can still thrive.

Build Dam

Though there are other possible solutions, these two combined would be the best. The dam would control the flow of the river, while the insurance would keep the town economically safe incase of a dam failure.