

AN INVESTIGATION INTO THE RELATIVE CONTRIBUTION OF ENGINEERING
COURSES IN THE DEVELOPMENT OF PROBLEM SOLVING AND THOUGHT
PROCESSES

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ABSTRACT

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An Investigation Into The Relative Contribution Of Engineering Courses In The Development
 Of Problem Solving And Thought Processes

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The study of engineering in high schools has recently become an innovative addition to the curriculum. This movement, as any new addition to the curriculum would, comes with many questions that need to be answered. The purpose of this study was to determine the relative contribution of an engineering curriculum in the development of the problem solving and thought processes. The research addresses whether or not there is there a difference between students in a non-technical class (art students) and an engineering class as well as a general physics class with regards to how they solve a structural problem within three iterations.

Two-hundred-fifty junior and senior students enrolled in engineering, art and physics classes were asked to attempt to solve a structural problem in three iterations. The objective of

the structural problem was to remove as much paper as possible, leaving two outer holes intact to hang their designed solution, while supporting a 500 gram weight. They were asked questions about how they formulated their solutions, what the results of the testing were, and to forecast or plan what they would do next.

The findings of this research tell us that engineering students (versus physics and art students) can attack problems with a higher consistency, relating their solutions to previous experiences and carry out their thought processes from concept to design more frequently. An engineering course is unique in nature and contributes significantly in the development of problem solving and thought processes. Engineering students used calculations and carried ideas forward to their next design more than art or physics students. When the mean weights of students successful solutions were compared, engineering students designed the lightest, followed by art and physics respectively. This study supports the findings of the National Science Foundation's recommendations that there is a need for more emphasis on teaching the process of a discipline and on developing critical thinking skills.

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CHAPTER ONE

Introduction

The study of engineering in high schools has recently become an innovative addition to the curriculum. This movement, as any new addition to the curriculum would, comes with many questions that need to be answered. The purpose of this study was to determine the relative contribution of an engineering curriculum in the development of the problem solving and thought processes. The research addresses whether or not there is there a difference between students in a non-technical class (art students) and an engineering class as well as a general physics class with regards to how they solve a structural problem within three iterations.

Teaching children specific content is important in order to develop their experiences and exposures, but within the heart of our educational system is simply teaching students to think.

Education must train one for quick, resolute and effective thinking. To think incisively and to think for one's self is very difficult. We are prone to let our mental life become invaded by legions of half truths, prejudices, and propaganda. Education must enable one to sift and weigh evidence, to discern the true from the false, the real from the unreal, and the facts from the fiction (King, Jr., 1947, 10).

The strengths that each individual brings have to be developed as well as their whole person. This is very different from offering a standardized set of facts and figures for each person to master, and then ranking people according to how well they do that (Yero, 2002). In his time Socrates searched for truth and knowledge. His students did not concentrate on one particular discipline or area of content. They focused on the learning process and how to think for themselves by asking appropriate questions that would lead to logical answers. This process

has stood the test of time. Content will change, evolve and disappear in the centuries to come yet teaching students to think will remain.

Problem solving is one of most valuable ways we think. Princeton Universities “Wordnet” defines problem solving as “The area of cognitive psychology that studies the processes involved in solving problems and the thought processes involved in solving a problem” (Princeton University, 1997). Many times students are taught what they can not do instead being taught to develop ideas. For example: if a fourth grade student and a veteran engineer were given the same problem to solve, who would generate the more creative ideas? More often than not the child, who has not been taught the limitations of materials or production techniques, will submit the more creative ideas. “Problem solving has been considered broadly as a higher form of learning which depends on other less complex forms of learning. It is seen as part of the process of investigation where the solution is not obvious to the researcher at the outset of the activity” (Okebukola, 1992, 153).

Social Science tries to do problem solving through social debate.

As they move from the middle grades to high school, students will need to think more deeply about how we can manage technology so that we control it rather than the other way around. There should be opportunities to confront such issues as the consequences of using robots to produce goods, the protection of privacy in the age of computers and electronic surveillance, and the opportunities and challenges of genetic engineering, test-tube life, and medical technology with all their implications for longevity and quality of life and religious beliefs (National Council for Social Studies [NCSS], 1994).

High School students are also poised to discuss and think systematically about personal, national and global decisions, interactions and consequences. These students may also need to recognize

and identify the rights and responsibilities of citizens and help set directions for public policy and participate in community services.

The study of mathematics tries to teach problem solving through quantities. Math courses use specific textbooks and their students do only those problems. Answers are single in nature and are incomplete or incorrect if they do not match the solution key for that chapter.

In any educational setting, students should build on their prior knowledge, learning more-varied and more-sophisticated problem-solving techniques. Students should increase their abilities to visualize, describe, and analyze situations in mathematical terms (National Council for Social Studies [NCSS], 1994). There are school programs that are now implementing and practicing what is called a Problem Solving Curriculum or PSC. What does this mean?

...it entails teaching students that they have the freedom to solve problems with a set of given tools and knowledgeable guidance and that the goal is to further develop their mathematical tool kit. It means having problems that lead students in the right directions for discussion and practice of new topics discovered (Schettino, 2003, 534).

The study of science tries to teach problem solving though exploring laws of nature. Problem solving is a critical part of science education, presumably because science in itself is basically concerned with exploring the universe and seeking answers to fascinating phenomena in nature.

In grades 9-12, design tasks should explore a range of contexts including both those immediately familiar in the homes, school, and community of the students and those from wider regional, national, or global contexts. Science should promote different ways to tackle the problems so that different design solutions can be implemented by different students. Successful completion of design problems requires that the students meet

criteria while addressing conflicting constraints. Where constructions are involved, these might draw on technical skills and understandings developed within the science program, technical and craft skills developed in other school work, or require developing new skills (National Committee on Science Education Standards and Assessment, National Research Council, 1996).

Engineering is a discipline that has been taught since the first formalized education program for engineers was established by the 1794 Congress that authorized the Corps of Artillerists and Engineers, assigning it to the garrison West Point. A definition of the engineering profession provides an answer to “what is engineering?” The Accreditation Board for Engineering and Technology (ABET) defines engineering as: “The profession in which knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to use, economically, the materials and forces of nature for the benefit of mankind.” Some secondary schools are experimenting with implementing engineering into their curriculum. While teachers can teach content with computers, it can also be stated that educators can’t teach with just computers. Students need to be given exposure to the creative nature of engineering through design projects, hands-on laboratories and open-ended problem solving (Sheppard & Jenison, 1996).

Engineering programs are missing in most secondary schools. This form of education connects science, technology, english and math (STEM), and may have a profound effect on how students view their educational experience. Math, science, and english instructors play significant roles in an engineering program as students work hard during their entire school day in other classes. An engineering program makes use of what they learn in these classes, combines it, applies it, and provides the opportunity to solve real world problems and case

studies. “Engineers apply the theories and principles of science and mathematics to solve technical problems. Frequently the engineer's work makes the connection between scientific discovery and real-world application” (Deal, 1994, 15).

Although teachers are doing more than they have in the past to give students opportunities to become technologically literate, too often educators place students in front of computers and assume that problem solving abilities and technological literacy follows. When colleges use surveys to find out what kinds of skills incoming college freshman have, their skills, including computer skills, are much lower than expected. Baylor University reported that 24% of engineering students have some experience use Computer Aided Design (CAD) software and that the expertise level on a scale of one to five was at one and only 63% of students were familiar with software like PowerPoint and then only at an expertise level of one out of five (DeJong, VanTreuren &, Faris, 2001).

The study of engineering makes a contribution to the development of problem solving and thinking. An engineering program should be organized around a set of concepts, skills and attitudes necessary to be successful in engineering. Unfortunately, students in schools can still graduate having had no practical contact with engineering concepts or case studies. Many students find all the choices in engineering schools intimidating because they enter college not understanding what engineering is and have to enter with their major listed as “engineering undecided” (Hedrick, 2002). The need for courses that stimulate interest in careers in engineering and technology has been apparent since the mid 1980’s. The 1955 Grinter Report (Grinter, 1955) led to a curriculum swing from practical engineering base to a scientific base with more emphasis on theoretical approaches and less emphasis on the “machinery” of engineering (Sheppard & Jenison, 1996). Colleges and universities soon realized there were

better ways of teaching young students as their courses were too theoretical in nature. In the middle to late 1960's, engineering educators began to react to the lack of understanding of design by their students by producing several studies that re-implemented design throughout their four year programs (Sheppard & Jenison, 1996). The transition between high school and college should be developed into a seamless operation to significantly increase the success of students.

Engineering education makes a contribution to the high school curriculum by providing an opportunity for students and teachers to link content together and apply it to solve problems. Many colleges and universities are still not attracting and retaining students in engineering programs. "Too many students become discouraged in the first few terms of an engineering curriculum and because of inadequate exposure to engineering and engineering design, many switch out of engineering" (Sheppard & Jenison, 1996). Many of these same college students are also unprepared for the level of required math and science it takes to be an engineering student. Working with college students in the ME99 course at Stanford, a mechanical dissection course sponsored by the National Science Foundation, it was realized that early exposure to engineering should start well before the freshman year in college (Sheppard & Tsai, 1992). Criticisms leveled at US engineering schools include: they offer too few "practical" and "hands-on" courses (Sheppard & Jenison, 1996).

According to Hoyt & Ohland, 1995, laboratories employ active learning and a smaller class size to achieve two objectives: (1) to better inform students about the nature of engineering and its specific disciplines and (2) improve these students retention in engineering (Hoyt & Ohland, 1995). Many schools are under budget restrictions and are increasing class sizes and not hiring new teachers to answer budget problems. It is not logical to create large sections of courses in order to satisfy allocation issues in schools at the expense of students. The first

engineering schools in the United States used the laboratory as the primary mode of instruction (Durfee, 1994). In 1938, John Dewey wrote:

The final justification of shops, kitchens, and so on in the school is not just that they afford opportunity for activity, but that they provide opportunity for the *kind* of activity or for the acquisition of mechanical skills which leads students to attend to the relation of means and ends, and then to consideration of the way things interact with one another to produce definite effects (Dewey, 1947, 106).

“For many industries, including manufacturing, nursing, and technology, current and future labor shortages stem from the fact that their workforces are getting older” (Challenger, 2003, 3). Every year the United States government accepts more and more people from foreign countries on work visas to place them in technology-related fields. The continued use of the H-1B visa program during one of the tech industry's most severe downturns has heightened renewed criticism of the program. It is a hot-button issue with many U.S. engineers who fear the country is giving away its tech jobs (Bjorhus, 2002).

Statement of the problem

Engineering education taught at the high school level is relatively new. Any curriculum innovation has to endure scrutiny by experts and professionals. It also has to prove how it contributes to the overall purpose and mission of education. Very little research has been done that establishes the merits of engineering ways of thinking designed for students for life, higher education and work in a technological society. Therefore engineering education has the potential to make a significant and unique contribution to the school curriculum. The purpose of this study was to determine the relative contribution of an engineering curriculum in the development of the problem solving and thought processes.

Research questions

The following questions will be addressed by this research:

1. Is there a difference between students in a non-technical class (art students) and an engineering student with regards to how they solve a structural problem within three iterations?

2. Is there a difference between students in a non-technical class (art students) and a physics student and how they solve a structural problem within three iterations?

3. Is there a difference between an engineering student and a physics student and how they solve a structural problem within three iterations?

Justifications or Significance

The data collected from the results of the student test provided an insight into the ability of an engineering education program at the high school level to provide unique problem solving techniques and strategies.

This problem is of major significance as many college programs and businesses have determined that early exposure to engineering education should start well before the freshman year in college (Sheppard & Tsai, 1992). An engineering education program at the high school level fills the requirements of businesses by developing a student's critical thinking and problem solving skills beyond what a math or science course expects of them. Business and industry demand that their employees have certain skill sets in order to be successful.

Assumptions/Limitations of the study

The researcher teaches the engineering course referenced in this information. A limitation is that the researcher is also influential on the engineering students in the study. It is also a limitation in that the research was conducted at Madison West High School only. It is an assumption the Madison Metropolitan School District and Madison West High School are

similar to other school districts. The findings were appropriate to those in the population for which the sample was taken. If other high schools within the state of Wisconsin and throughout the nation have similar school structure and classes, the results may be applicable.

Definition of terms

Accreditation Board for Engineering and Technology: ABET, Inc., the recognized accreditor for college and university programs in applied science, computing, engineering, and technology, is a federation of 31 professional and technical societies representing these fields. Among the most respected accreditation organizations in the U.S., ABET has provided leadership and quality assurance in higher education for over 70 years. ABET currently accredits some 2,500 programs at over 550 colleges and universities nationwide. ABET is recognized by the Council on Higher Education Accreditation.

Allocation: The amount of time set aside for an instructor as part of a contract. For example, Sally was given a sixty percent contract allocation for the three classes she teaches.

Art students: Students enrolled in Madison West High School that are enrolled an art class in Madison, Wisconsin semester one 2003-2004.

At risk students: students who may be learning at a level below their current grade and/or may not pass courses to move into the next grade.

Blooms taxonomy: In 1956, Benjamin Bloom headed a group of educational psychologists who developed a classification of levels of intellectual behavior important in learning. Bloom found that over 95 % of the test questions students encounter require them to

think only at the lowest possible level...the recall of information. Bloom identified six levels within the cognitive domain, from the simple recall or recognition of facts, as the lowest level, through increasingly more complex and abstract mental levels, to the highest order which is classified as evaluation. Higher level skills are listed in the Analysis, Synthesis and Evaluation sections. Verb examples that represent intellectual activity on each level are listed in table one.

Table 1

Blooms taxonomy

Level	Verb examples
Knowledge	arrange, define, duplicate, label, list, memorize, name, order, recognize, relate, recall, repeat, reproduce, state.
Comprehension	classify, describe, discuss, explain, express, identify, indicate, locate, recognize, report, restate, review, select, translate
Application	apply, choose, demonstrate, dramatize, employ, illustrate, interpret, operate, practice, schedule, sketch, solve, use, write
Analysis	analyze, appraise, calculate, categorize, compare, contrast, criticize, differentiate, discriminate, distinguish, examine, experiment, question, test
Synthesis	arrange, assemble, collect, compose, construct, create, design, develop, formulate, manage, organize, plan, prepare, propose, set up, write
Evaluation	appraise, argue, assess, attach, choose compare, defend estimate, judge, predict, rate, core, select, support, value, evaluate

Engineering students: Students enrolled in the Madison West High School engineering 1 class in Madison, Wisconsin semester one 2003-2004.

Epistemology: The branch of philosophy that studies the nature of knowledge, its presuppositions and foundations, and its extent and validity.

H-1B visa: The H-1B nonimmigrant visa may be issued to individuals who seek temporary entry in a specialty occupation as a professional. Some examples of "specialty occupations" include accountant, computer analyst, engineer, financial analyst, scientist, architect or lawyer. The petition can be approved with a combination of college or university course work plus three years work experience for each year of university education missing. Together this would be deemed equivalent to a four-year bachelor's degree.

Hands on: Involving active participation; applied, as opposed to theoretical.

Heuristics: Of or constituting an educational method in which learning takes place through discoveries that result from investigations made by the student.

Iteration: The act or an instance of iterating; repetition. One cycle of a set of instructions to be repeated.

No Child Left Behind Act: The No Child Left Behind Act of 2001 (No Child Left Behind) is a landmark in education reform designed to improve student achievement and change the culture of America's schools. President George W. Bush describes this law as the "cornerstone of my administration." Clearly, our children are our future, and, as President Bush has expressed, "Too many of our neediest children are being left behind" (United States Department

of Education [USDE], 2001). With passage of No Child Left Behind, Congress reauthorized the Elementary and Secondary Education Act (ESEA)--the principle federal law affecting education from kindergarten through high school. In amending ESEA, the new law represents a sweeping overhaul of federal efforts to support elementary and secondary education in the United States. It is built on four common-sense pillars: accountability for results; an emphasis on doing what works based on scientific research; expanded parental options; and expanded local control and flexibility (United States Department of Education [USDE], 2001).

Physics students: Students enrolled in the Madison West High School general physics class in Madison, Wisconsin semester one 2003-2004.

Problem solving: the area of cognitive psychology that studies the processes involved in solving problems (Princeton University, 1997).

Soft skills: interpersonal skills that are important non-technically oriented characteristics that employers are looking for. These soft skills are usually common sense. For example, cultural adaptability, ability to get along with others or an ability to communicate clearly and effectively.

Technologically literate: A person who understands — with increasing sophistication — what technology is, how it is created, how it shapes society, and in turn, how technology is shaped by society is technologically literate. A person can hear a story about technology on television or read it in the newspaper and evaluate its information intelligently, put that

information in context, and form an opinion based on it. A technologically literate person is comfortable with and objective about the use of technology —neither scared of it nor infatuated with it (Gomez, 2002, vii).

CHAPTER TWO

Literature review

The study of engineering in high schools has recently become an innovative addition to the curriculum. This movement, as any new addition to the curriculum would, comes with many questions that need to be answered. The research addresses whether or not there is a difference between students in a non-technical class (art students) and an engineering class as well as a general physics class with regards to how they solve a structural problem within three iterations.

The literature review will discuss human cognitive psychology, a brief history of education as well as several ways we teach children in schools today. It will also provide insight and documentation to support the research that was done to determine the relative contribution of engineering courses in the development of problem solving and thought processes. Many historical references like the Grinter report of 1955 are given and many recent references like the Powers American Society for Engineering Education (ASEE) document from 2003 confirm that indeed our students need better critical thinking and problem solving skills before they graduate from high school.

School and thinking

We are sent to school to be civilized and socialized. Knowledge is better than ignorance. “As a nation, we have concluded that it is better for us all if all of us go to school. In an aspiring nation in the age of the Industrial Revolution, it became a matter of political economy to have educated citizens” (Fulghum, 1990, 88). In our current society, we still believe that it is important to send our children off to school to be introduced and subjected to society.

Thomas Jefferson first proposed, in 1779 to the Virginia Legislature, that all children be educated at public expense, but it was not until well into the next century that such a plan was put into place, and even then without enthusiasm on the part of the public. The idea was resisted by a substantial part of the population, sometimes with armed force. As late as the 1880's the law had to be enforced in some towns by militia who marched children to school under guard. In the 1890's, public opinion shifted just enough to create a reform movement in education. There were major problems with labor conflicts, immigration issues and economic depression. These worries fostered the concerns associated with education and the questions regarding whether public schools were doing their part to morally educate and culturally adjust the youth of the day. Many people then thought that schools were not teaching these values and were merely memorization factories. Politics were also under reform, the two movements were largely labeled "progressive" in nature. Many school districts actively tried to disassociate themselves with the politics in larger cities. Smaller school districts hired "captains of education" to run their schools. Schools of education rolled out research projects on differences between students, the specialization of curriculum for individual students and how to motivate students.

The tension between the two goals of progressive education--efficiency and individual growth--went unrecognized by many reformers, who patched together new ideas and programs in a general effort to make schools more relevant to the world of work and more responsive to children's individual needs. Many educators embraced scientific efficiency and the industrial metaphor without qualms (Kaestle, 1990, 32).

While these issues were pressing the politics in the system, John Dewey and his associates were working on a balance between a child's interest and the knowledge of adults. This work produced a curriculum that engaged students in cooperative, active work and

integrated social and intellectual learning. Providing children with first hand experiences was the banner of John Dewey's pedagogy. In 1916 he wrote:

There must be more actual material, more *stuff*, more appliances, and more opportunities for doing things, before the gap can be overcome. And where children are engaged in doing things and in discussing what arises in the course of their doing, it is found, even with comparatively indifferent modes of instruction, that children's inquiries are spontaneous and numerous, and the proposals of solutions advanced, varied, and ingenious (Dewey, 1966, 156).

Separate schools for vocational education were defeated in most places, the most extreme schemes failed because they sounded too undemocratic. This "child centered" mentality faced opposition from parents, teachers and Dewey himself. Educators preferred that any reforms be efficiency related and not child centered. By the time the late 1950's came, Life Adjustment Education came about through an effort to combine efficiency and child centered theme. It was an intellectually weak program that gave way to another round of reforms that replaced it.

Thinking and problem solving

Thinking is usually a more conscious effort than lower level cognitive processes like perception. When we see certain objects in our everyday lives, we typically are not aware of the process our mind goes through to identify those objects. Similarly, we are not always aware of the retrieval of information while we are having a conversation. We are much more aware of the process that we go through when we solve math problems or decide to order ice cream. "Usually, thinking is hard. People typically learn how to recognize objects simply via everyday experience. By contrast, we can program a computer to play chess better than most humans, but

we have much less information about how to get a computer to recognize an object” (Shah, 2000).

Thinking in and of itself has been argued to be a behavior by cognitive psychologists. Behavior is defined by the fourth edition of the American Heritage dictionary as “The actions or reactions of a person or animal in response to external or internal stimuli” (Houghton Mifflin, 2000). Some psychologists support this, some do not. However, both sides of the debate do agree that more specific study needs to be done to determine how we decide the things we do. “Relatively little time and energy have been invested in understanding why we think—the factors that make us start or stop thinking, choose and change strategies and solutions” (Overskeid, 2000, 134). Several studies in the last three decades have investigated the factors influencing a person’s way of thinking and drawing conclusions. These studies have revealed some scholarly information regarding the mapping of heuristics and biases, evolutionary influences on thinking, motivated reasoning and mood effects on problem solving. However, all have fallen short in defining what the mechanism is that motivates us to choose one idea over another, or pursue one avenue of a problem versus the next. Clearly there may never be a way of actually defining why a person makes the choices that they do.

Research on problem solving and the history of science points out that if a problem is looked at from a new or different perspective, new questions as well as new answers may be formed (Kauffman, 1989; Kuhn, 1970). Many contemporary evaluations of teaching are still encouraging educators to move beyond teaching the facts, and toward teaching thinking and process (Eisen, 1998). A National Science Foundation (NSF) report titled Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology stressed a number of proven approaches to science education and recommends their

integration at all educational levels (National Science Foundation [NSF], 1996). These recommendations include a need for more emphasis on teaching the process of the discipline; on developing critical thinking skills; on addressing the current applications and implications of the information being taught; on encouraging collaboration among students, both in and out of class; and on developing writing and speaking skills.

Thinking can be broken down into three different categories. These three categories are as follows; “*information processing*, which has its roots in the dominant paradigm in cognitive psychology, *making judgments*, which is associated with critical thinking, and *sense making* which is embedded in constructivist epistemology” (McGuinness, 1993, 305). Information processing theories seek to explain mental events, the cognitive phenomena that intervene between stimuli and responses. These cognitive events are best understood as symbolic representations and processes that act upon these mental representations in real time. These representations and processes are structures into a coherent functional system or cognitive architecture which may account for performance over a wide variety of tasks. “Thinking skills are thought to be general in nature and can be transferred beyond the context in which they are acquired” (McGuinness, 1993, 306).

Critical thinking can be defined many different ways. Researchers have compiled information and surveys to form their own definitions and most have similar themes within them. The most comprehensive definition comes from a consensus statement in a Delphi report compiled from forty-six experts in the field of critical thinking:

Critical thinking is essential as a tool of inquiry. As such, critical thinking is a liberating force in education and a powerful resource in one's personal and civic life. While not synonymous with good thinking, critical thinking is a pervasive and self-rectifying

human phenomenon. The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit (Facione, 1990).

Critical thinking is about the ability to connect the mind and a person's ability to respond to a problem. "The critical thinker must be able to analyze arguments, identify assumptions, judge credibility, and spot logical errors in inferences and so on" (McGuinness, 1993, 307).

Thinking can also be regarded as "sense making." This view also has many different definitions such as the traditional Piagetian position that asserts that knowledge is primarily constructed from actions which regulate our interactions with the world. This means that "Mental representation is a form of internalized action which is coordinated and organized into qualitatively different cognitive structures. Imbalances, or dis-equilibration, lead to the reorganization of cognition structures" (McGuinness, 1993, 307). The constructivist position is advocated mainly by educational theorists, particularly science educators. Constructivist epistemology is many times offset or has contrast with logical positivism or empiricism (Novak, 1987) which holds that 'true' knowledge corresponds to how the world really works, the goal of knowing is to discover this true knowledge. In contrast, constructivism contends that knowledge is the invention of human minds and to gain knowledge is to maneuver through a series of conceptual structures. "Teachers and students are viewed as active meaning-makers who continually give contextually based meanings to each others' words and actions as they interact" (Cobb, 1988, 88). This constructivist viewpoint on education considers the learner as an active

source of meaning and sees instruction as cooperation between two sets of conceptual structures, the teacher's and the learner's. Thinking is therefore just about sense making. The goal of this is about knowledge restructuring and not about teaching skills and strategies. Learners “actively construct an individual worldview based upon personal observation and experience and that they respond to formal instruction in terms of this preexisting intuitive perspective” (Linn, 1986, 6).

Science and the standards

The National Committee on Science Education Standards and Assessment as well as the National Research Council worked together in 1996 to create the National Science Standards. These standards have emphasized that our world is filled with scientific products and scientific literacy should be a necessity for everyone. People need to use scientific information to make choices that come about every day. They also need to be able to converse intelligently about important issues that involve science and technology.

Scientific literacy also is of increasing importance in the workplace. More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the processes of science contribute in an essential way to these skills. Other countries are investing heavily to create scientifically and technically literate work forces. To keep pace in global markets, the United States needs to have an equally capable citizenry. The Standards ask for more than "science as process." Students need to learn such skills such as observing, inferring, and experimenting. Inquiry is also essential in science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and

logical thinking, and consider alternative explanations (National Committee on Science Education Standards and Assessment, National Research Council, 1996).

Science and thought processes

The American Heritage Dictionary of the English Language, Fourth Edition defines science as “the observation, identification, description, experimental investigation, and theoretical explanation of phenomena or knowledge...obtained and tested through scientific method” (Houghton Mifflin, 2000). “To generate knowledge, a scientist must learn to achieve interplay among four traits: curiosity, creativity, critical-thinking abilities, and knowledge of rigorous testing procedures. The entire process, from curiosity to the generation of new knowledge, is the scientific method” (Isaak & Hubert, 1999, 321). Science as inquiry is basic to science education and a controlling principle in the ultimate organization and selection of students' activities.

The National Science standards on inquiry emphasize the ability to conduct inquiry and develop understanding about scientific inquiry. Courses in science, from Kindergarten through 12th grade and in every domain of science should provide the opportunity for students to:

Use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments (National Committee on Science Education Standards and Assessment, National Research Council, 1996).

As in any profession, philosophy changes, new ideas are born and change becomes inevitable. The aim of reform in science education has been to enhance student achievement and

to broaden access to science in order to increase the scientific literacy of citizens in general (Fensham, 1988). Co-operative learning has been one of the larger efforts in this reform, and may be the answer to the evolution from the traditional science classroom. Dr. Robert Edward Slavin of Johns Hopkins University defines co-operative learning as:

The provision of a classroom environment in which students work together on academic tasks in small heterogeneous groups. In this form of classroom organization students use each other as a resource for knowledge and ideas. Cooperative learning and the environment that is created by it should increase the level of mutual support and collaboration between students and is viewed as a means of improving student achievement and cognitive skills (Slavin, 1984, 55).

Slavin also goes on to say that academic achievement, social and affective development and improved relations across ethnic groups can be expected. Findings in relation to student attainment when exposed to co-operative learning techniques have been mixed. Slavin (1983) in a review, found that in 63% of projects concluded that student achievement was enhanced. "Practical and problem-solving skills and concepts related to specific areas of the curriculum are more likely to be enhanced through co-operative learning approaches" (Qualter & Abu-Hola, 2000, 238).

People often see the teaching community as faddish--every year a different approach is "in." One decade "individualized instruction" is the way to go, and the next decade teachers are told to teach with "cooperative learning." In science education, discovery learning was popular in the 1960s, and then came inquiry, then STS (science/technology/society). Today, inquiry and discovery are back again (Colburn, 2000, 9).

Engineering and thought processes

Engineers across the nation are taught problem solving skills through courses they take in college. These skills can be taught through mathematics or science courses but have much more meaning in laboratory courses that use open ended problems or case studies as their foundation. Many educators believe that our educational system teaches students to solve problems using “cook-book” procedures, instead of teaching students how to solve problems in effective ways (Elger, Beller, Beyerlein &, Williams, 2003). This way of teaching is strange to most students as they have been conditioned to being told the right answer, instead of researching, developing and creating the answer themselves.

Too often, the concept of problem solving skills is confused with the ability of students to solve problems. How a student approaches the problem, whether it be a calculus assignment or a lab experiment, is more important than just finding the correct solution. Understanding these skills can aid the student in a variety of other courses (Rockland, 1999).

Students need to be given the freedom to investigate possibilities and not relegated to the expectation of what is known to be the “correct” answer. If the solution has particular parameters placed on it and those parameters are met, the students have accomplished their task. The “plug and chug” method of regurgitation of information that is presented by a teacher is quite traditional, as is the retention rate of that information from year to year. Experts also agree that

The importance of understanding memory in the classroom is that memory determines what students know and can do. Memory not only creates the bridge between successive experiences, making it possible to learn from them, but it also determines how

experiences are related to each other and how what is learned changes over time. The design of effective instructional programs must take into account how remembering and forgetting occur (Nuthall, 2000, 133).

The road to the solution is just as important, if not more important as finding the solution itself. Educators need to teach the learning process that students require in order to navigate that road. Students typically retain more in the classroom if they hear it, see it and then do it. Students must be allowed to investigate and explore open ended problems that allow them to create the answer. Dr. Alan H. Schoenfeld of the University of California at Berkeley writes:

Most textbooks present “problems” that can be solved without thinking about the underlying mathematics, but blindly applying the procedures that have just been studied. Typical classroom instruction subverts understanding even further by providing methods for solving problems that allow students to answer problems correctly, without making an attempt to understand them (Schoenfeld, 1988, 163).

Real world problem solving involves an understanding of the complex interaction among various fundamental sciences, environmental, social, economic and ethical issues as well as computationally based analysis and design. Teaching students to think in a manner that would encompass these issues is needed at all levels of education (Powers, 2003).

Expert cognitive psychologists have defined two different areas within problem solving. The first, meta-cognition or “thinking about ones thought process” entails knowledge, awareness and control of one’s thinking. “Activities such as planning how to approach a given learning task, monitoring comprehension, and evaluating progress toward the completion of a task are metacognitive in nature” (Livingston, 1997, 1). Within metacognition, the individual engages in an active and deliberate process of monitoring their problem solving process. The other,

Schema, refers to how one organizes their knowledge in long term memory. Schema is a hierarchical mental structure similar to a spider web where links or connections are made between relevant facts and concepts. Large concepts are at center of the web, secondary concepts are in the middle radii of the web and facts and details are at the outer radii of the web. “Schema can involve procedural knowledge; that is, a schema can organize common patterns that facilitate problem solving. A few engineering educators have recognized the importance of schema for procedural knowledge” (Elger et al., 2003). Wales Nardi &, Stager (1986) used a schema named the professional decision making process and a teaching method called guided design to teach thinking skills to freshman students. To assess the effect of guided design, Wales et. al., analyzed ten years of data, 5 years pre-guided design and 5 years post. The data showed that when thinking skills were taught, the number of students who ultimately graduated increased by 32%. Also, the average grade point average at graduation was up by 25% (Wales, 1979).

Most people rely on two or three methods to solve problems. If these methods don't yield a successful answer, they become stuck. Truly exceptional problem solvers learn to use multiple problem-solving techniques to find the optimum solution. The following is a list of possible tools or strategies that can help solve simple problems (Gomez, Oakes &, Leone, 2004 315-316):

1. Look for a pattern
2. Construct a table
3. Consider possibilities systematically
4. Act it out
5. Make a model
6. Make a figure, graph or drawing

7. Work backwards
8. Select appropriate notation
9. Restate the problem in your own words
10. Identify necessary, desired and given information
11. Write an open-ended sentence
12. Identify a sub-goal
13. First solve a simpler problem
14. Change your point of view
15. Check for hidden assumptions
16. Use a resource
17. Generalize
18. Check the solution; validate it
19. Find another way to solve the problem
20. Find another solution
21. Study the solution process
22. Discuss limitations
23. Get a bigger hammer
24. Sleep on it
25. Brainstorm
26. Involve others

Problem solving can be broken into analytic problem solving and creative problem solving. Most students are more familiar with analytic problem solving where there is one

correct answer. In creative problem solving there is no single right answer. Analytic tools represent what's in ones toolbox. Creative skills represent how one handles their tools.

Analytic problem solving

Analytic problem solving can be described as a disciplined way of approaching engineering problems. One of the most important analytic problem-solving; methods that students are exposed to is the Scientific Method. The scientific method is defined by The American Heritage Dictionary of the English Language, Fourth Edition as:

The principles and empirical processes of discovery and demonstration considered characteristic of or necessary for scientific investigation, generally involving the observation of phenomena, the formulation of a hypothesis concerning the phenomena, experimentation to demonstrate the truth or falseness of the hypothesis, and a conclusion that validates or modifies the hypothesis (Houghton Mifflin, 2000).

In the Scientific Method, the steps can be repeated if the desired results are not achieved. The process ends when an acceptable understanding of the phenomenon under study is achieved. Further description of the scientific method is as follows:

1. Observe some aspect of the universe.
2. Invent a tentative description, called a hypothesis, which is consistent with what you have observed.
3. Use the hypothesis to make predictions.
4. Test those predictions by experiments or further observations and modify the hypothesis in the light of your results.
5. Repeat steps 3 and 4 until there are no discrepancies between theory and experiment and/or observation.

When consistency is obtained the hypothesis becomes a theory and provides a coherent set of propositions which explain a class of phenomena. A theory is then a framework within which observations are explained and predictions are made.

In the analysis of engineering applications, a similar process can be developed to answer problems. The advantage of developing a set method for solving analytic problems is that it provides a discipline to help young engineers when they are presented with larger and more complex problems.

Analytic problem solving method

The Analytic Problem solving method has six steps (Gomez et al., 2004, 317-320).

1. Define the problem and make a problem statement. It is important to restate the problem that is being solved in your own words. In textbook problems, this helps to define what it is that needs to be solved. In real life situations, this helps to ensure that the correct problem is being solved.
2. Diagram and describe the problem and list all that is known. In addition to restating the problem, list the information given and what needs to be found. Formally writing out what is needed and what is required helps to clearly sort this out. It is also helpful to draw a diagram or sketch of the problem that is being solved to be able to understand the problem. Pictures help many people to clarify the problem and what is needed. They are also a great aid when explaining the problem to someone else.
3. Apply theory and equations. State explicitly the theory or equations needed to solve the problem. It is important that these are written out completely at this step. Most real problems will not require exact solutions to complete equations.

4. Simplify any assumptions. Engineering and scientific applications often cannot be solved precisely. Even if they are solvable, determining the solution might be cost prohibitive. Simplifying assumptions can make the problem easier to solve and still provide an accurate result. It is important to write the assumptions down along with how they simplify the problem. This documents them and allows the final result to be interpreted in terms of these assumptions.

5. Solve the necessary problems. Perform the calculations needed. This might be done by hand or by using the computer. When using computer simulations, develop a means to document what has been done in deriving the solution.

6. Verify accuracy to the required level. Several verification methods are:

Estimate the answer.

Simplify the problem and solve the simpler problem. Are the answers consistent?

Compare with similar solutions. In many cases, other problems were solved similarly to the one currently in question.

Compare to previous work.

Ask a more experienced engineer to review the result.

Compare to published literature on similar problems.

Ask yourself if it makes sense.

Compare to your own experience.

Repeat the calculation.

Run a computer simulation or model.

Redo the calculation backwards.

Creative Problem Solving

Many engineering problems are open-ended and complex. Such problems require creative problem solving. To maximize the creative problem-solving process, a systematic approach is used. By dividing the process into steps, a complete and careful problem-solving procedure and more effective solutions result.

John F. Kennedy said in an address to the American University in 1963, “Our problems are man-made, therefore they may be solved by man. And man can be as big as he wants. No problem of human destiny is beyond human beings” (Kennedy, 1963). A large, complex problem is broken into simpler problems where various skills can be used. The creative process is not a theory or something that cannot be defined. “It is simply the exercise of the higher-level skills listed in Bloom’s taxonomy: analysis, synthesis and evaluation” (Jessop, 2002). Throughout their education students spend much of their brainpower on the lower-level skills, which inhibits, but does not impede their progress to the critical thinking or higher-levels.

Creative problem solving method

One way to look at the creative problem-solving process is through asking a set of six questions (Gomez et al., 2004). What is wrong? In the first step of the problem-solving process, an issue is identified. This can be something stated for you by a supervisor or a professor, or something you determine on your own. This is the stage where entrepreneurs thrive-looking for an opportunity to meet a need. Similarly, engineers look to find solutions to meet a need. This may involve optimizing a process, improving customer satisfaction, or addressing reliability issues.

What is known? The second step in problem solving is the gathering of facts. All facts and information related to the problem identified in the first step are gathered. In this initial

information gathering stage, do not try to evaluate whether the data is central to the problem. Premature evaluation can be a barrier to generating sufficient information.

What is the real problem? This stage is one that is often skipped, but it is critical to effective solutions. The difference between this stage and the first is that this step of the process answers the question why. Identifying the initial problem answers the question of what, or what is wrong. To effectively fix the problem, a problem solver needs to understand why the problem exists. The danger is that only symptoms of the problem will be addressed, rather than root causes.

What is the best solution? Once the problem has been defined, potential solutions need to be generated. This can be done by oneself or with the help of friends. In an engineering application, it is wise to confer with experienced experts about the problem's solution. This may be most productive after a list of causes has been generated. The expert can comment on any generated list and offer their own. This is a great way to get ideas critiqued. After more experience is gained by an individual, technical experts can help narrow down the choices rather than provide more. Also, go to more than one source. This may provide more ideas as well as help with the next step.

How can the solution be implemented? This step is a critical phase of the problem solving process. In engineering applications, implementation can be a very critical phase of the process. Most of the solutions to problems either require additional resources including money or the cooperation of other groups that are either not directly affected by the problem or not under ones control. Implementation does not necessarily end the problem solving process. Just as the design process is a circular process with each design leading to possible new designs,

problem solving can also be cyclic. Once a solution has been found and implemented, an evaluation should be performed.

Estimation

Estimation can provide quick answers to problems and to verify complicated analyses. While estimation or approximation may not yield the precision required for an engineering analysis, it is a very useful tool. One thing that it can do is help check an analysis. The method chosen may be correct, but one character mistyped will throw your results off. Estimation can also be used to help decide if a detailed analysis is needed. Estimating using a best case and worst case scenario can yield an upper and lower bound on the problem. If the entire range of potential solutions is acceptable, why do the detailed analysis? Brian Lisles, General Manager of Newmann Hass Racing and former crew chief of legendary race car driver Mario Andretti explains estimation:

I remember my last day at work...the report was done, I thought, I better just make sure this model is realistic. So I sat down and did some hand calculations. When I was finished with the hand calculations, it was within 5% of what the computer program said it would be. Because my finite element analysis (FEA) program was not very accurate anyway it would have been easier to have just done the hand calculations in the first place. I was pleased that the hand calculations and the FEA results were about the same. If you understand what you're doing, you can get results to your problem quickly (B. Lisles, personal communication, July 5th, 2003).

Novice and Expert Problem Solvers

“Experts have about 50,000 “chunks” of specialized knowledge and patterns stored in their brains in a readily accessible fashion” (Simon, 1979, 363). These experts have information in their brains linked and typically do not store disconnected facts.

Accumulation of the linked knowledge takes about ten years. Since it is not feasible to accumulate this much information in four or five years, producing experts is not a realistic goal of engineering education. However, it is reasonable to mold proficient problem solvers who have the potential to become experts after more seasoning (Wankat & Oreovicz, 1993, 68).

Novices or students have little for prerequisites and should be encouraged to do deep processing, practice defining problems and working sketches and paraphrase the problems statement while looking at different ways to solve the problem. “Students should also practice analyzing problems to break the problem into parts, and they need to be encouraged to perform the explore step” (Wankat & Oreovicz, 1993, 69). Instructors should take the role of motivator and encourage students to solve the problem, but not solve it for them or lead them in any way. Correction of a student or group of students by an instructor may lead to a different direction though. A comparison of novice and expert problem solvers is illustrated in table two below (Wankat & Oreovicz, 69-70).

Table 2

The comparison of novice and expert problem solvers

Characteristic	Novices	Experts
Memory	Small pieces Few items	“Chunks” or patterns ~50,000 items
Attitude	Try once and then give up Anxious	Con-do if persistent Confident
Categorize	Superficial details	Fundamentals
Problem statement	Difficulty re-describing Slow and inaccurate Jump to conclusions	Many techniques to re-describe Fast and accurate Take time defining tentative problem May redefine several times
Simple, well defined problems	Slow Work backward	~ 4 times faster Work forwards with known procedures
Strategy	Trial and error	Use a strategy
Information	Don’t know what is relevant Cannot draw inferences from incomplete data	Recognize relevant information Can draw inferences
Parts (harder problems)	Do NOT analyze into parts	Analyze parts Proceed in steps Look for patterns
First step done (harder problems)	Try to calculate (first step done)	Define and draw Sketch Explore
Sketching	Often not done	Considerable time Abstract principles Show motion
Limits	Do not calculate	May calculate to get a quick fix on solution
Equations	Memorize or look up detailed equations for each circumstance	Use fundamental relations to derive needed result

Solution procedures	“Un-compiled” Decide how to solve after writing equation	“Compiled” procedures Equation and solution method are single procedure
Monitoring solution in progress	Do not do	Keep track Check off versus strategy
If stuck	Guess Quit	Use Heuristics Persevere Brainstorm
Accuracy	Not concerned DO NOT check	Very accurate Check and recheck
Evaluation of result	Do not do	Do from broad experience

Iteration Design

An iteration can be defined as the act or an instance of iterating, repetition. Many people use the term “re-iterate” in conversation, and never understand its direct meaning, repeating ones-self. Students in engineering whether they are in high school or college will attack problems with rigor and stamina, often into the early morning hours. Often these late nights or “all-nighters” occur shortly before a solution is due for presentation or competition. Here in lies the problem. There is usually little attention given to testing the solution. Students (high school and college) need to be shown the importance of iteration in design and testing. “Design calls for iterations. Many alternatives need exploring when style is a goal. As a result, industrial designers need a short feedback loop in the design process and must make changes using continual feedback” (Staples, 2003).

Mathematics uses iterations as a computational procedure in which a cycle of operations is repeated, often to approximate the desired result more closely. Computer Science defines iterations as the process of repeating a set of instructions a specified number of times or until a

specific result is achieved. It can also be described as one cycle of a set of instructions to be repeated as in “after ten iterations, the program exited the loop.”

Through the test conducted in this study, it became apparent to students that their solutions improved after a few tries at it. Education spends far too little time on this. For example, if students were assigned to build a balsa wood bridge, they should spend the first part of the experience researching and coming up with possible solutions through different processes, depending on which type of course it is happening in. Then, when they agree on a design, they begin to build it. Often this takes many days and can even push into over a week. By the time testing comes, they may have encountered problems, failures or had visions of some other way that they could “do it better”, but never get the chance. The due date is usually upon them. It is suggested that teachers forego more complex problems with no opportunity for iterations for simpler problems that can be solved multiple times.

...the systems of equations that must be solved to determine the truth-values are often "non-linear"--so attempts to find a solution can rarely be found in the general case, but must be found numerically, closing in on the answer through several iterations of trial and error (Economist, 2003, 77).

John Dewey

John Dewey's central concern was centered on the formation of good ideas. These ideas were defined very broadly as: depictions, words, explanations, mental images, etc.

He (Dewey) wanted to know how in goal oriented, communal (conjoint or cooperative) activities of humans made possible thought communications, that we can ensure that we are successful; in taking the most important step- arriving at good ideas- in surmounting difficulties and in solving problems (Mina, Omidvar &, Knott, 2003).

His philosophy aimed at creating conditions that ensure the continued possibility of realizing one's successful ability to form good ideas: solutions, decisions, depictions, explanations etc. Dewey's theory of inquiry and his philosophies of education are similar to those in engineering education (Mina et. al., 2003).

Dewey's philosophy is based on organisms. These organisms exist in a given environment that has been created, one that exists already.

The basic importance of the serial relation in logic is rooted in the conditions of life itself. Modification of both organic and environmental energies is involved in life-activity. This organic fact foreshadows learning and discovery, with the consequent outgrowth of new needs and new problematic situations...What the organism learns during this process produces new powers that make new demands upon the environment.

In short, as special problems are resolved, new ones tend to emerge (Dewey, 1938, 35).

When a bear is hungry it will seek out food. Through the experience of finding the food, the bear creates a storage of knowledge that could be developed into a habit. In higher order animals like humans, this would be an actual memory that will again help to find food in the future. Through the series of actions that organisms go through to return to equilibrium, their methods are refined and improved. This is quite similar to the American Heritage Dictionary of the English Language, Fourth Edition definition of evolution: "A gradual process in which something changes into a different and usually more complex or better form" (Houghton Mifflin, 2000). Dewey defined the aim of life as growth, which he identified as a self-renewing process through action upon the environment. John Dewey wrote in 1920:

The process of growth, improvement and progress, rather than the static outcome and result, becomes the significant thing...Not perfection as a final goal, but the ever

enduring process of perfecting, mastering, refining is the aim in living. Honesty, industry, temperance, justice, like health, wealth and learning, are not goods to be possessed as they would be if they expressed fixed ends to be attained. They are directions of change in the quality of experience (Dewey, 1948, 177)

Dewey went on to describe that students need to apply the formal things learned in our schools to some life building or meaningful application. Many primitive societies may not have formalized education, but what they do learn is then practiced and taught to their children or members of their community so that they can use it to prosper. “When the acquiring of information and of technical intellectual skill do not influence the formation of a social disposition, ordinary vital experience fails to gain in meaning, while schooling, in so far, creates only “sharps” in learning- that is, egotistic specialists” (Dewey, 1916, 9).

Dewey’s theory of inquiry is similar to the scientific method. “He has also termed it the process of inquiry, critical or reflective thinking, or a complete act of thought” (Mina et al., 2003). These steps can be closely aligned with the process that engineering students go through while planning, organizing and solving problems.

Mina et al., 2003, reports these five steps of thinking as

1. A felt difficulty
2. Its location and definition
3. Suggestion of possible solutions
4. Development by reasoning of the bearings of the suggestion
5. Further observation and experiment leading to its acceptance or rejection; that is, the conclusion of belief or disbelief

Dewey's theory of inquiry has major implications that are important to engineering education. The following four quotes include many of Dewey's philosophies and formally summarize what may or may be leading our students to become less and less interested in science, technology, engineering and math (STEM) careers.

First, Dewey argues that knowledge never leaves the realm of theory and remains forever subject to change.

No matter how certain scientists and engineers are about a theory they use to explain their activities and their decisions, a theory never leaves the realm of "guess," and scientists should forever leave open the possibility that their firmest ideas and most cherished solutions may need to be modified or scrapped. The effectiveness of science and engineering emanates exactly from this characteristic of science. Engineers and scientists would do well to pass on this mindset to their students by creating an environment that genuinely encourages this skeptical attitude in students (Mina et al., 2003).

This statement asks the instructor or expert to loosen up a little and be flexible enough to let the students question things in a positive manner. What this statement does not encourage is a negative attitude towards life or any teaching that is presented to them.

Dewey argues that all inquiry involves transforming the environment; it is an activity. Knowledge building is transformative in nature. For Dewey, an inquiring mind is going to change the environment in some way and disrupt the way things have always been done. It however needs to understand and respect the history of how things were done, but will not define those ways of doing things as the answer so much that a new way is not investigated. Instructors may have to evolve their curriculum and overall teaching strategies. This may involve capital investments in order to change or evolve the facilities that exist or the supplies that are needed

for the projects, prototypes and case studies. This philosophy asks educators to define what the term evolution means to them. As in a good history lesson, educators need to remember where they have been in order to determine where they are going, and make sure not to “throw the baby out with the bathwater.”

Dewey also argues that facts are facts in the context of inquiry. In 1938 he wrote:

In logical fact, perceptual and conceptual materials are instituted in functional correlativity with each other, in such a manner that the former locates and describes the problem while the latter represents a possible method of solution (Dewey, 1938, 111).

Teaching facts outside the context is counterproductive. Many classes in our education system teach facts to students and then expect them to regurgitate them back on an assessment a few days later. These facts, when taught in a contextual or applied manner may stay with a student longer and become more meaningful to them, thus intrinsic and automatically stored in their brain in an organized, connected manner so that they can readily retrieve the information at a later date. In 1916 John Dewey explained why there was a negative stigma regarding an individual’s level of knowledge regarding persons who worked with their hands in the arts:

Science, or the highest knowing, was then identified with pure theorizing, apart from all application in the uses of life; and knowledge relating to useful arts suffered the stigma attaching to the classes who engaged in them (Dewey, 1966, 229).

Dewey emphatically argues against teaching students the findings of science as canned ideas to believe in. Instead of repeating the hypothetical and theoretical things that science already knows, students should understand the theories in a context of significant investigation.

There is no such thing as experiment in the scientific sense unless action is desired by some leading idea....The moment they are taken to be first truths in themselves there ceases to be any reason for scrupulous examination (Dewey, 1947, 109).

What Dewey is describing is that science and its experimentation methods are not truly experimental. It attaches more importance, not less to ideas as ideas. The intent of true problem solving is to have students design and create their own learning in the form of solutions that they develop. The problems students solve should be designed and chosen so that they have a direct impact or meaning to the students. These problems should build in the information from the scientists who came up with the theories and ensure that they are used in a contextual or applied manner. There should also be ample time in the curriculum for students to engage in authentic experimentation and inquiry, a time to ask the question “what if?” Students should be guided safely with the knowledge and guidance of the instructor so that they aren’t investigating a road that could lead to a hazardous, dangerous or unsafe situation. It should also be noted that sometimes these “what if” paths are traveled and the results can produce things that can be beneficial to society.

Conclusion

Through this chapter, a wide array of teaching techniques, topics and philosophies have been presented. We have seen the educational pendulum swing back and fourth over many years and it is safe to say that it will continue to do so in the future. What we need to assure is that our students evolve with the times enough to be viable employees and informed citizens. Our curriculums have to reflect the thoughts and needs of the communities we live in and the businesses that reside in those communities. As early as 1904, John Dewey criticized “the willingness of our teaching corps to accept without inquiry or criticism any method or device

which seems to promise good results. Teachers...flock to those persons who give them clear-cut and definite instructions as to just how to teach this or that” (Dewey, 1904).

Education should be a cooperative effort to supply our students with the best experiences possible, utilizing every resource possible. “One cannot expect world class learning of science, mathematics and problem solving techniques by students if U.S. teachers lack the confidence, enthusiasm, and knowledge to deliver world-class instruction” (National Science Board [NSB], 1999).

CHAPTER THREE

Methodology

Description of methodology

The study of engineering in high schools has recently become an innovative addition to the curriculum. This movement, as any new addition to the curriculum would, comes with many questions that need to be answered. The purpose of this study was to determine the relative contribution of an engineering curriculum in the development of problem solving and thought processes. The research addresses whether or not there is a difference between students in a non-technical class (art students) and an engineering class as well as a general physics class with regards to how they solve a structural problem within three iterations.

Two-hundred-fifty junior and senior students were asked to attempt to solve a structural problem in three iterations. Iterations are a significant portion of this research as “Design calls for iterations. Many alternatives need exploring when style is a goal. As a result, industrial designers need a short feedback loop in the design process and must make changes using continual feedback” (Staples, 2003). The objective of the structural problem was to remove as much paper as possible, leaving two outer holes intact to hang the solution, while supporting a 500 gram weight. Students were asked questions about how they formulated their solutions, what the results of the testing were, and to forecast or plan what they would do next.

The research that was conducted was comparative in nature. Experimental research was not used because it was not feasible to randomly assign participants into groups; they had already been assigned to groups based on the courses they enrolled in. They were given consent forms to have signed and those students who agreed to be a part of the research participated in the study in the 18th week of semester one 2003-2004.

Research design

The dependent variables observed included weight of tested solutions and several areas that were examined on a secondary question sheet of paper for each solution that students designed. These were:

1. Why did you cut the paper like you did?
2. Why do you think it succeeded/failed?
3. What's your next idea?

Each response was categorized and then ranked in order of their percentages. The top ranked responses were used in the charting of results in chapter four. The responses with very low or no percentage totals were dropped from the analysis as there was little or no data to evaluate.

Subjects

The two hundred-fifty participants involved in this research were students enrolled in general physics, engineering, and art classes at Madison West High School in Madison, Wisconsin. General physics students were selected as they are taught theory in scientific principles. Engineering students were selected, as they are taught the application of theoretical and factual science while infusing technical information and the freedom to be creative in idea generation. Art students were selected to provide information on what abilities students have that are not taught scientific and mathematical theory or their applications. Art students are taught that there can be freedom in idea generation and are shown that they can go beyond what has been done or known and make something on their own. For more information about Madison West High School, see appendix F.

Instrumentation

Students filled out a demographic survey (see appendices B, C and D) that consisted of seven general questions before they began the testing. Each student was given the instrument on three sets of three hole punched colored paper (green, yellow and red) with codes on each set that were anonymous (see appendix E). These codes consisted of labels with letters and numbers. The letters identified the course, general physics (GP) and a number kept track of the student, anonymously (01). The engineering students were given the same sheets using a letter (E) for engineering and a number (01). The art students were given the same sheets using a letter (A) for art and a number (01). The objective of the instrument was to remove as much paper as possible, leaving the two outermost holes intact to hang the solution, while supporting a 500 gram weight. Students tested their designs by weighing their solution to the nearest centigram and hanging the paper structure they created on an apparatus. They then hung the 500 gram weight from their solution and recorded the results. They were also asked to answer three questions regarding each iteration of the problem that were mentioned in the previous research design section.

Procedures

On January 8, 2004 Human Subjects Consent forms were sent to the parents of 250 students. The form used is available in Appendix A within this document. Forms were due back in no later than January 12, 2004 and all 250 students were approved for the study.

The 32 apparatus' for testing were constructed by the researcher, checked and measured to obtain consistent measurements between apparatus' (See Appendix G). A tolerance of .0375 inches was used in the spacing of the dowel rods mounted on the apparatus that the paper will fit onto. The weights students used to test their solutions were gathered and measured in order to

determine their exact weight and dimensions. All 32 weights were found to be exactly the same in grams. Weights were measured with a .050 gram tolerance. The centigram scales used for measuring student solutions were electronically and manually calibrated using internal electronics of the scales and a certified 300 gram calibration weight on January 12, 2004. Instructors from each class to be tested were briefed on the procedures to be used when administering the instrument to insure consistency between all.

On January 13, 2004 47 students in two different art classes were administered the instrument. On January 14, 2004 48 students in two different engineering classes were administered the instrument. On January 15, 2004 146 students in seven different physics classes were administered the instrument (see appendix E for the instrument). The instructor that supervised students used the following procedures and instructions:

The objective of the test is to remove as much paper as possible while supporting the given weight. The end result will be strength to weight ratio of the provided 500 gram weight to the weight of the paper structure created.

1. Your proctor will distribute envelopes that contain three different sets of colored paper, make sure that the codes on the papers are all the same and match the code on the front of the envelope.
2. Your proctor will have testing apparatus', scissors and pencils for you to use during the test. Insure that all items are in good condition and exchange any as necessary.
3. Fill out the 7-question survey BEFORE you begin the test.
4. The green set of paper is for your first trial. The yellow set of paper is for your second trial. The red set of paper is for your third trial.

5. The codes at the top of the paper must be visible when you are finished. If you have removed the code, or cut it, please re-write the code on your final product.
6. You must leave the two punched holes at either end of the paper INTACT, as this is where it will be hung on the apparatus.
7. Answer the three questions on the last page BEFORE you go on to the next try.
8. You must weigh your solution (in grams) and record it BEFORE you hang it on the apparatus for testing.
9. Use the provided 500 gram weight for testing
10. You have 50 minutes to complete all three trials. Please return ALL paper to the envelope provided, even if they are scraps.

Instructors assured that each student weighed and recorded their solutions before testing each time. Instructors also insured that the survey was completed and all materials were placed back into their original envelopes and collected. The materials used for the test (scissors, weights and apparatus) were inspected to insure integrity for any subsequent tests.

Limitations

The researcher teaches the engineering course referenced in this information. A limitation is that the researcher is also influential on the engineering students in the study. It is also a limitation in that the research was conducted at Madison West High School only. It is an assumption the Madison Metropolitan School District and Madison West High School are similar to other school districts. The findings were appropriate to those in the population for which the sample was taken. If other high schools within the state of Wisconsin and throughout the nation have similar school structure and classes, the results may be applicable.

Data analysis

A number of statistical analyses were used in this study. The Statistical Program for Social Sciences, version 12.0, (SPSS, 2004) was used to analyze the data. Frequencies and percentages were calculated for the demographics and chi squared analysis were performed on all the data leading to significant and insignificant findings.

CHAPTER FOUR

Results

The study of engineering in high schools has recently become an innovative addition to the curriculum. This movement, as any new addition to the curriculum would, comes with many questions that need to be answered. The purpose of this study was to determine the relative contribution of an engineering curriculum in the development of problem solving and thought processes. The research addresses whether or not there is there a difference between students in a non-technical class (art students) and an engineering class as well as a general physics class with regards to how they solve a structural problem within three iterations.

Two-hundred-fifty junior and senior students enrolled in engineering, art and physics classes were asked to attempt to solve a structural problem in three iterations. The objective of the structural problem was to remove as much paper as possible, leaving the two outermost holes intact to hang the solution, while supporting a 500 gram weight. They were asked questions about how they formulated their solutions, what the results of the testing were, and to forecast or plan what they would do next.

Rate of response

Two-hundred-fifty students (juniors and seniors) were given consent forms to obtain permission from their parent(s) or legal guardian in order to participate in the study. Every student was approved for the study, which resulted in a rate of participation of 100% (n=250). All students participated in the study, however nine students results had to be discarded as they returned packets that had incomplete or invalid information. Several students that completed the entire test may have left out an answer to one demographic or not had time to finish the third iteration. These cases are noted throughout this chapter in the charts as missing data.

Demographics

Participants were asked to answer several questions in the survey that prefaced the test. All questions were asked in multiple-choice items. Table three indicates the gender of the participating students and the percent of the sample, yielding data at the nominal scale of measurement.

Table 3

Gender of participants

	Frequency	Percent
Male	123	51
Female	118	49
Total	241	100

There were a total of 241 participants, 118 (49%) were female and 123 (51%) were male.

Participant’s course and their gender were compared. Table four reports the breakdown pertaining to which class they were enrolled in. It also represents the gender breakdown within each independent course.

Table 4

Participants gender and course

	Engineering student		Physics student		Art student	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Female	7	14.58	83	56.85	28	59.57
Male	41	85.42	63	43.15	19	40.43
Total	48	100	146	100	47	100

When the participants were separated by their course and compared to their gender the following was found. The engineering course had 19.9 % (n=48) of the participants in the study. Of these engineering students, 14.6% (n=7) were female and 85.4% (n=41) were male. The physics course had 60.6 % (n=146) of the participants in the study. Of these physics students, 56.8% (n=83) were female and 43.2 (n=63) were male. The art course had 19.5% (n=47) of the participants in the study. Of these art students, 59.6% were female and 40.4% (n=19) were male. It is to be noted that there were two sections of engineering courses, seven sections of general physics courses, and two sections of the art class tested. Therefore all of the available sections in the courses desired for study were incorporated into the research.

Participant’s cumulative grade point average (GPA) was measured in multiple-choice items, yielding data at the ordinal scale of measurement. Table five reports number and the percentage of participant’s GPA’s

Table 5

Participants Grade Point Average (GPA)

Category	Frequency	Percent
3.5 - 4.0	118	49
3.0 - 3.4	87	36.1
2.5 - 2.9	26	10.8
2.0 - 2.4	8	3.3
1.9 and under	0	0

Of the 241 students that completed the test, two students failed to note their grade point average on the survey, however all other information and the test was complete. It was because of this completeness that their results remained as part of the research. The breakdown of GPA’s

was: 49% (n=118) of the participants grade point average was between 3.5 and 4.0, 36.1% (n=87) of participants grade point average was between 3.0 and 3.4, 10.9% (n=26) of the participants grade point average was between 2.5 and 2.9, 3.3% (n=8) of the participants grade point average was between 2.0 and 2.4. No participant’s grade point average was below 2.0.

Participants cumulative Grade Point Average (GPA) were separated by gender. Table six reports how many male and female students were represented in each of the grade point average areas.

Table 6

Participants gender and GPA

	3.5-4.0	3.0-3.4	2.5-2.9	2.0-2.4	1.9 and under
Female	68	42	4	3	0
Male	50	45	22	5	0

Of the total number of females who participated in the study (n=118), the breakdown of GPA’s was: 57.6% (n=68) of the participants grade point average was between 3.5 and 4.0, 35.6% (n=42) of participants grade point average was between 3.0 and 3.4, 3.4% (n=4) of the participants grade point average was between 2.5 and 2.9, 2.5% (n=3) of the participants grade point average was between 2.0 and 2.4. No participant’s grade point average was below 2.0.

Of the total number of males that participated in the study (n=123), the GPA breakdown was: 40.7% (n=50) of the participants grade point average was between 3.5 and 4.0, 36.6% (n=45) of participants grade point average was between 3.0 and 3.4, 17.9% (n=22) of the participants grade point average was between 2.5 and 2.9, 4.1% (n=5) of the participants grade point average was between 2.0 and 2.4. No participant’s grade point average was below 2.0.

Table seven represents the relationship between groups and their grade point average or their gender. Grade point averages were grouped into five categories as represented in the previous tables.

Table 7

Relationship between groups and their GPA or their gender

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
GPA	95	3	.504	191	3	.047	192	3	.205
Gender	95	1	.000	193	1	.742	194	1	.000

There was a significant difference in grade point averages between physics participants and art participants. 63.8% of art participants had a grade point average above 3.5, while only 31.4% of physics participants had a grade point average over 3.5.

There was significant difference in gender between engineering participants and art participants. Females represented 59.6% of the population in the art participants while females represented only 6.86% of the engineering participants.

There was also a significant difference in gender between engineering participants and physics participants. Females represented 56.8% of physics participants while females represented only 6.9% of the engineering participants.

Participant’s highest level of math course completed was measured in multiple-choice items, yielding data at the nominal scale of measurement. Table eight reports how many of the participants and the percentage of participant’s level of math completed.

Table 8

Participants level of math class completed

	Frequency	Percent
consumer math	4	1.7
algebra	22	9.1
geometry	117	48.5
algebra 2	69	28.6
advanced math/algebra3	18	7.5
statistics	1	.4
calculus	9	3.7

For the participants in this study, the breakdown of level of math completed was 1.7% (n=4) consumer math, 9.1% (n=22) algebra, 48.5% (n=117) geometry, 28.6% (n=69) algebra 2, 7.5% (n=18) advanced math or algebra 3, .4% (n=1) statistics, and 3.7% (n=9) calculus.

Participant's highest level of math course completed was measured in multiple-choice items, yielding data at the nominal scale of measurement. Table nine reports how many of the participants and the percentage of participant's level of math completed and course participated in.

Table 9

Participants highest level of math completed and course tested in

	Engineering student		Physics student		Art student	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
consumer math	0	0	1	.68	3	6.38
algebra	2	4.17	5	3.42	15	31.91
geometry	9	18.75	97	66.44	11	23.40
algebra 2	18	37.5	37	25.34	14	29.79
advanced math/algebra 3	13	27.08	4	2.74	1	2.13
statistics	0	0	1	.68	0	0
calculus	6	12.5	1	.68	2	4.26

The top math course completed by the engineering participants (37.5% (n=18)) as seen in table nine was algebra 2. The top math course completed by the physics participants (66.44% (n=97)) as seen in table nine was geometry. The top math course completed by the art participants (31.91% (n=15)) as seen in table seven was algebra.

Participant's highest level of math completed and course participated in were compared using a chi squared analysis. Table 10 reports the relationship between groups and their highest level of math completed.

Table 10

Relationship between groups and their highest math course completed

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
consumer math	95	1	.075	193	1	.017	194	1	.565
algebra	95	1	.000	193	1	.000	194	1	.811
geometry	95	1	.578	193	1	.000	194	1	.000
algebra 2	95	1	.426	193	1	.548	194	1	.105
advanced math/algebra 3	95	1	.001	193	1	.818	194	1	.000
statistics	95	-	-	193	1	.569	193	-	-
calculus	95	1	.148	193	1	.085	194	1	.000

There was a significant difference in level of math course completed (algebra) between engineering participants and art participants. 31.91% of art participants completed algebra as their highest course, whereas only 4.17% of engineering participants completed algebra as the highest math course. There was also a significant difference in engineering and art participants highest level of math completed (advanced math/algebra 3) in that 27.08% of engineering participants reported that their highest level of math was advanced math or algebra 3, while only 2.13% of art participants reported that their highest level of math was advanced math or algebra 3.

Between the physics and art participants there was a significant difference in level of math class completed (consumer math/pre algebra) as 6.38% of art students reported that their highest level of math was consumer math/pre algebra, while only 0.7% of physics students

completed consumer math/pre algebra as their highest math course. There was a significant difference in physics and art participants level of math class completed (algebra) in that 31.91% of art participants reported that their highest level of math was algebra, while only 3.40% of physics participants reported that their highest level of math was algebra. There was also a significant difference in physics and art participants level of math class completed (geometry) in that 66.44% of physics participants reported that their highest level of math was geometry, while 23.40% of art participants reported that their highest level of math was geometry.

There was a significant difference between engineering and physics participants in level of math class completed (geometry) as 66.44% of physics students reported that their highest level of math was geometry, while 18.75% of engineering students completed geometry as their highest math course. There was a significant difference in engineering and physics participants level of math class completed (advanced math or algebra 3) in that 27.08% of engineering participants reported that their highest level of math was advanced math or algebra 3, while only 2.72% of physics participants reported that their highest level of math was advanced math or algebra 3. There was also a significant difference in engineering and physics participants level of math class completed (calculus) in that 12.5% of engineering participants reported that their highest level of math was calculus, while 0.7% of physics participants reported that their highest level of math was calculus.

Participant's highest level of science course completed was measured in multiple-choice items, yielding data at the nominal scale of measurement. Table 11 reports how many of the participants and the percentage of participant's level of science completed.

Table 11

Participants level of science class completed

	Frequency	Percent
biology 1 or 2	26	10.8
introduction to physical science	9	3.7
earth science	5	2.1
chemistry or chemistry in the community	171	71
general physics or accelerated math physics	26	10.8

For the participants in this study, the breakdown of level of science completed was 10.8% (n=26) biology 1 or 2, 3.7% (n=9) introduction to physical science, 2.1% (n=5) earth science, 71% (n=171) chemistry or chemistry in the community, 10.8 (n=26) general physics or accelerated math physics.

Participant's highest level of science completed and course participated in was compared. Table 12 reports how many of the participants and the percentage of participant's level of science completed and course participated in.

Table 12

Participants highest level of science completed and course tested in

	Engineering student		Physics student		Art student	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
biology 1 or 2	4	8.33	2	1.38	20	42.55
intro to physical science	0	0	7	4.83	2	4.26
earth science	0	0	3	2.07	2	4.26
chemistry or chemistry in the community	23	47.92	133	91.73	15	31.91
general physics or math physics	21	43.75	0	0	5	10.64

The top course completed by the engineering participants (47.92% (n=23)) as seen in table 12 was chemistry or chemistry in the community. The top course completed by the physics participants (91.73% (n=133)) as seen in table 12 was chemistry or chemistry in the community. The top course completed by the art participants (42.55% (n=20)) as seen in table 12 was biology 1 or 2.

Participant's highest level of science completed and course participated in were compared using a chi squared analysis. Table 13 reports the relationship between groups and their highest level of science completed.

Table 13

Relationship between groups and their highest level of science completed

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
biology	95	1	.000	192	1	.000	193	1	.016
physical science	95	1	.149	192	1	.872	193	1	.121
earth science	95	1	.149	192	1	.413	193	1	.315
chemistry or chemistry in the community	95	1	.111	192	1	.000	193	1	.000
general/math physics	95	1	.000	192	1	.000	193	1	.000

There was a significant difference in level of science course completed (biology) between engineering participants and art participants. 42.6% of art participants completed biology as their highest course, whereas only 8.3% of engineering participants completed biology as the highest science course. There was also a significant difference in engineering and art participants highest level of science completed (general/math physics) in that 43.8% of engineering participants reported that their highest level of science was general/math physics, while only 10.6% of art participants reported that their highest level of level of science was general/math physics.

Between the physics and art participants there was a significant difference in level of science class completed (biology) as 42.6% of art students reported that their highest level of science was biology, while only 1.4% of physics students completed biology as their highest science course. There was a significant difference in physics and art participants level of science

class completed (chemistry or chemistry in the community) in that 91.7% of physics participants reported that their highest level of science was chemistry or chemistry in the community, while 31.9% of art participants reported that their highest level of science was chemistry or chemistry in the community. There was also a significant difference in physics and art participants level of science class completed (general/math physics) in that 10.6% of art participants reported that their highest level of science was general/math physics, while 0.0% of physics participants reported that their highest level of science was general/math physics. This last statement can be explained as the physics participants were enrolled in the very course that was being compared and therefore no participant would be able to respond that they completed the course.

There was a significant difference between engineering and physics participants in level of science class completed (biology) as 8.3% of engineering students reported that their highest level of science was biology, while 1.4% of physics students completed biology as their highest science course. There was a significant difference in engineering and physics participants level of science class completed (chemistry or chemistry in the community) in that 91.7% of physics participants reported that their highest level of science was chemistry or chemistry in the community, while 47.9% of engineering participants reported that their highest level of science was chemistry or chemistry in the community. There was also a significant difference in engineering and physics participants level of science class completed (general/math physics) in that 43.8% of engineering participants reported that their highest level of science was general/math physics, while 0.0% of physics participants reported that their highest level of science was general/math physics. This last statement can be explained as the physics participants were enrolled in the very course that was being compared and therefore no participant would be able to respond that they completed the course.

Participant's highest level of engineering course completed was measured in multiple-choice items, yielding data at the nominal scale of measurement. Table 14 reports how many of the participants and the percentage of participant's level of engineering completed.

Table 14

Participants level of engineering completed

	Frequency	Percent
computer aided design (CAD)	17	7.1
materials science	6	2.5
engineering 1, 2 or engineering management	12	5.0
CAD and materials science	0	0
CAD and engineering 1, 2 or engineering management	23	9.5
materials science and engineering 1, 2, or engineering management	2	.8

For the participants in this study, the breakdown of level of engineering completed was 7.1% (n=17) CAD, 2.5% (n=6) materials science, 5.0% (n=12) engineering 1, 2 or engineering management, 0% (n=0) CAD and materials science, 9.5% (n=23) CAD and engineering 1, 2 or engineering management, 0.8% (n=2) materials science and engineering 1, 2, or engineering management.

Participant's highest level of engineering course completed was measured in multiple-choice items, yielding data at the nominal scale of measurement. Table 15 reports how many of the participants and the percentage of participant's level of engineering completed and course participated in.

Table 15

Participants highest level of engineering completed and course

Course	Engineering student		Physics student		Art student	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Computer aided design (CAD)	0	0	10	6.85	7	14.90
materials science	0	0	5	3.42	1	2.13
engineering 1, 2 or engineering management	11	22.92	1	.068	0	0
CAD and materials science	0	0	0	0	0	0
CAD and engineering 1,2 or engineering management	23	47.92	0	0	0	0
materials science and engineering 1, 2, or engineering management	2	4.17	0	0	0	0

The top course completed by the engineering participants (47.92% (n=23)) as seen in table 15 was CAD and engineering 1, 2 or engineering management. The top course completed by the physics participants (6.85% (n=10)) as seen in table 15 was computer aided design (CAD). The top course completed by the art participants (14.90% (n=7)) as seen in table 15 was CAD.

Participant's highest level of engineering completed and course participated in were compared with a chi squared analysis. Table 16 reports the relationship between groups and their highest level of engineering completed.

Table 16

Relationship between groups and highest level of engineering completed

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
CAD	95	1	.005	193	1	.091	194	1	.063
materials science	95	1	.310	193	1	.656	194	1	.194
engineering 1,2 or engineering management	95	1	.000	193	1	.569	194	1	.000
CAD & materials	95	-	-	193	-	-	194	-	-
CAD & engineering	95	1	.000	193	-	-	194	1	.000
materials science & engineering	95	1	.157	193	-	-	194	1	.013

There was a significant difference in level of engineering course completed (CAD) between engineering participants and art participants. Art participants (14.9%) completed CAD as their highest course, whereas 0.0% of engineering participants completed CAD as the highest engineering course. There was also a significant difference in engineering and art participants highest level of engineering completed (engineering 1, 2 or engineering management) in that 22.9% of engineering participants reported that their highest level of engineering was engineering 1, 2 or engineering management, while 0.0% of art participants reported that their highest level of engineering was engineering 1, 2 or engineering management. There was a significant difference in level of engineering course completed (CAD & engineering) between engineering participants and art participants. Engineering participants (47.9%) completed CAD

& engineering as their highest course, whereas 0.0% of art participants completed CAD & engineering as the highest engineering course.

There was a significant difference in engineering and physics participants highest level of engineering completed (engineering 1, 2 or engineering management) in that 22.9% of engineering participants reported that their highest level of engineering was engineering 1, 2 or engineering management, while 0.7% of art participants reported that their highest level of engineering was engineering 1, 2 or engineering management. There was a significant difference in level of engineering course completed (CAD & engineering) between engineering participants and physics participants. Engineering participants (47.9%) completed CAD & engineering as their highest course, whereas 0.0% of physics participants completed CAD & engineering as the highest engineering course.

Participants were asked whether or not they have tinkered with or taken things apart. This question was measured with a yes or no answer. Table 17 reports the frequency and percent of participants regarding tinkering and taking things apart.

Table 17

Participants that said they tinkered with or have taken things apart

	Frequency	Percent
Yes	192	79.7
No	49	20.3

For the participants in this study, 79.7% (n=192) said they have tinkered with or taken things apart and 20.3% (n=49) said they had never tinkered with or taken things apart.

Participants involved were asked whether or not they have tinkered with or taken things apart. This question was compared to the course they participated in and was measured with a yes or no answer, yielding data at the nominal scale of measurement. Table 18 reports how many of the participants and the percentage of participant’s that said they have “tinkered” and course participated in.

Table 18

Did participant tinker with or take things apart and course tested in

	Engineering student		Physics student		Art student	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
yes	41	85.4	114	78.1	37	78.7

The breakdown of participants in this study that said they have tinkered with or taken things apart was 85.4% (n=41) engineering participants, 78.1% (n=114) physics participants, 78.7% (n=37) art students.

Participants involved were asked whether or not they have helped a family member or neighbor work on projects that involved putting something together or designing something. This question was measured with a yes or no answer. Table 19 reports the frequency and percent of students regarding helping putting something together or designing.

Table 19

Participants that said they helped family or neighbor design or work on a project

	Frequency	Percent
Yes	178	73.9
No	63	26.1

Table 19 reveals that 73.9% of students that participated in this study have at some point helped a family member or neighbor design or work on a project.

Participants were asked whether or not they have helped family or neighbor design or work on a project. This question was compared to the course they participated in and was measured with a yes or no answer, yielding data at the nominal scale of measurement. Table 20 reports how many of the participants and the percentage of participant’s that said they have helped a family member or neighbor design or work on a project and course participated in.

Table 20

Participant helped family or neighbor design or work on a project and course tested in

	Engineering student		Physics student		Art student	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
yes	38	79.2	110	75.3	30	63.8

The breakdown of participants in this study that said they have helped family or neighbor design or work on a project was 79.2% (n=38) engineering participants, 75.3% (n=110) physics participants, 63.8% (n=30) art students.

Sketching and calculations

Participant’s submissions were observed for their use of sketching or calculations on their solutions or their scrap paper, yielding data at the nominal scale of measurement. Table 21 reports how many of the participants and the percentage of participant’s that used sketching or calculations.

Table 21

Participant used sketching or calculations

	Frequency	Percent
Used sketching	74	30.7
Used calculations	3	2.1

Table 21 reveals that 30.7% (n=74) of students that participated in this study used sketching on their solution or scrap paper and 2.1% (n=3) used calculations on their solution or scrap paper.

Participant’s submissions were observed for their use of sketching or calculations on their solutions or their scrap paper, yielding data at the nominal scale of measurement. Table 22 reports how many of the participants and the percentage of participant’s that used sketching or calculations and course participated in.

Table 22

Participants that used sketching or calculations and course tested in

Factor	Engineering student		Physics student		Art student	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Used sketching	23	47.9	38	26.0	13	27.7
Used calculations	3	6.3	0	0	0	0

The breakdown of participants in this study that used sketching on their solution or scrap paper was 47.9% (n=23) engineering participants, 26.0% (n=38) physics participants, and 27.7% (n=13) art students. The breakdown of participants in this study that used calculations on their

solution or scrap paper was 6.3% (n=3) engineering participants, 0.0% (n=0) physics participants, and 0.0% (n=0) art students.

Groups were compared regarding the participant’s use of sketching or calculations and course participated in. Table 23 reports the relationship between groups and their use of sketching or calculations.

Table 23
Relationship between groups and their use of sketching or calculations

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
Used sketching	95	1	.082	193	-	-	194	1	.002
Used calculations	95	1	.042	193	1	.825	194	1	.005

There was a significant difference between engineering and art participants and their use of calculations on their solution or their scrap paper. 6.3% of engineering students used calculations on their solution or their scrap paper, 0.0% of art students used calculations on their solution or their scrap paper.

There was a significant difference between engineering and physics participants and their use of sketching on their solution or their scrap paper. Engineering students (47.9%) used sketching on their solution or their scrap paper, 26.0% of physics students used sketching on their solution or their scrap paper. There was a significant difference between engineering and physics participants and their use of calculations on their solution or their scrap paper. Engineering students (6.3%) used calculations on their solution or their scrap paper, 0.0% of physics students used calculations on their solution or their scrap paper.

*Instrument measures**Iteration one*

Within the instrument, participants weighed their solution in grams; this can be measured in a numerical value and therefore can be given a mean measurement. This numerical value is represented in table 24 by the course that participants completed the test in.

Table 24

The weight of tested solutions, reported by groups, for iteration one

	Engineering student	Physics student	Art student
Mean weight	3.15	3.02	2.78

The iteration one mean weights for students participating in the three different groups were: engineering participants 3.15 grams, physics participants 3.02 grams, and art participants 2.78 grams.

Within iteration one, students were asked to answer the question “Why did you cut the paper like you did?” There were eight categories based on participant’s responses. The top four responses were ranked according to overall percentages and are listed in table 25 below. The remaining four responses were dropped from the study as there were very few in number. Table 25 represents the relationship between groups and their answers to the question.

Table 25

Iteration one, the relationship between groups and why they said they cut their solution

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Strength of material	95	1	.351	193	1	.161	194	1	.813
2 Hole location/weight distribution	95	1	.001	193	1	.447	194	1	.000
3 Reduce material	95	1	.395	193	1	.572	194	1	.123
4 Didn't cut	95	1	.414	193	1	.041	194	1	.198

There was a significant difference between engineering and art participants and their answer to the number two ranked answer to question one in iteration one. Engineering participants (45.8%) said they cut their solution as they did because of hole location or weight distribution, 14.9% of art participants said they cut their solution as they did because of hole location or weight distribution.

There was a significant difference between physics and art participants and their answer to the number four ranked answer to question one in iteration one. Physics participants (15.7 %) said they didn't cut their solution, 4.3% of art participants said they didn't cut their solution.

There was a significant difference between engineering and physics participants and their answer to the number two ranked answer to question one in iteration one. Engineering participants (45.8%) said they cut their solution like they did because of hole location or weight distribution, 19.9% of physics participants said they cut their solution like they did because of hole location or weight distribution.

Within iteration one, students were asked to answer the question “Why do you think it succeeded/failed?” There were nine categories based on participant’s responses. The top four responses were ranked according to overall percentages and are listed in table 26 below. The remaining five responses were dropped from the study as there were very few in number. Table 26 represents the relationship between groups and their answers to the question.

Table 26

Iteration one, the relationship between groups and why they said their solution succeed/failed

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Thickness	95	1	.826	193	1	.110	194	1	.171
2 Area around hole(s)	95	1	.969	193	1	.871	194	1	.833
3 Strength of materials	95	1	.296	193	1	.873	194	1	.248
4 Distribution of weight	95	1	.349	193	1	.412	194	1	.722

There were no significant differences between groups and their answers to question two in iteration one.

Within iteration one, students were asked to answer the question “What’s your next idea?” There were eight categories based on participant’s responses. The top three responses were ranked according to overall percentages and are listed in table 27 below. The remaining nine responses were dropped from the study as there were very few in number. Table 27 represents the relationship between groups and their answers to the question.

Table 27

Iteration one, the relationship between groups and what they said their next idea was

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Reduce material	95	1	.031	193	1	.252	194	1	.135
2 Modify from previous	95	1	.001	193	1	.190	194	1	.004
3 Fold	95	1	.039	193	1	.485	194	1	.076

There was a significant difference between engineering and art participants and their answer to the number one ranked answer to question three in iteration one. Art participants (36.2%) said they cut their solution like they did because they wanted to reduce material, 16.7% of engineering participants said they cut their solution like they did because they wanted to reduce material. There was also a significant difference between engineering and art participants and their answer to the second ranked answer to question three in iteration one. Engineering participants (45.8%) said they cut their solution like they did because they wanted to modify it from a previous design, 14.9% of art participants said they cut their solution like they did because they wanted to modify it from a previous design. There was a significant difference between engineering and art participants and their answer to the number three ranked answer to question three in iteration one. Art participants (29.8%) said they cut their solution like they did because they wanted fold it, 12.5% of engineering participants said they cut their solution like they did because they wanted fold it.

There was a significant difference between engineering and physics participants and their answer to the number two ranked answer to question three in iteration one. Engineering participants (45.8%) said they cut their solution like they did because they wanted to modify it from a previous design, 24.0% of physics participants said they cut their solution like they did because they wanted to modify it from a previous design.

Within iteration one participants that successfully held the weight and their answers to the question “Why did you cut the materials like you did?” were analyzed. There were eight categories based on participant’s responses. The top four responses were ranked according to overall percentages and are listed in table 28 below. The remaining four responses were dropped from the study as there were very few in number. Table 28 represents the relationship between groups and their answers to the question if they held the weight.

Table 28

Iteration one, participant’s structures that held the weight, compared to why they said they cut it

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Strength	95	1	.426	193	1	.607	194	1	.641
2 Hole location/weight distribution	95	1	.041	193	1	.850	194	1	.010
3 Reduce materials	95	1	.972	193	1	.333	194	1	.310
4 Didn’t cut	95	1	.414	193	1	.094	194	1	.384

There was a significant difference between engineering and art participants and their answer to the number two ranked answer to question one in iteration one if they successfully

held the weight. Engineering participants (27.1%) said they cut their solution like they did because of hole location or weight distribution, 10.6% of art participants said they cut their solution like they did because of hole location or weight distribution.

There was a significant difference between engineering and physics participants and their answer to the number two ranked answer to question one in iteration one if they successfully held the weight. Engineering participants (27.1%) said they cut their solution like they did because of hole location or weight distribution, 11.6% of physics participants said they cut their solution like they did because of hole location or weight distribution.

Iteration two

Within the instrument, participants weighed their solution in grams; this can be measured in a numerical value and therefore can be given a mean measurement. This numerical value is represented in table 29 by the course that participants completed the test in.

Table 29

The weight of tested solutions, reported by groups, for iteration two

	Engineering student	Physics student	Art student
Mean weight	1.91	2.63	2.22

The iteration two mean weights for students participating in the three different groups were: engineering participants 1.91 grams, physics participants 2.63 grams, and art participants 2.22 grams.

Within iteration two, students were asked to answer the question “Why did you cut the paper like you did?” There were eight categories based on participant’s responses. The top four responses were ranked according to overall percentages and are listed in table 30 below. The

remaining four responses were dropped from the study as there were very few in number. Table 30 represents the relationship between groups and their answers to the question.

Table 30

Iteration two, the relationship between groups and why they said they cut their solution

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Based on previous test	95	1	.118	193	1	.439	194	1	.006
2 Reduce material	95	1	.960	193	1	.618	194	1	.574
3 Hole location/weight distribution	95	1	.616	193	1	.887	194	1	.627
4 Strength of materials	95	1	.147	193	1	.320	194	1	.419

There was a significant difference between engineering and physics participants and their answer to the number one ranked answer to question one in iteration two. Engineering participants (52.1%) said they cut their solution like they did based on a previous test, 30.1% of physics participants said they cut their solution like they did based on a previous test.

Within iteration two, students were asked to answer the question “Why do you think it succeeded/failed?” There were nine categories based on participant’s responses. The top four responses were ranked according to overall percentages and are listed in table 31 below. The remaining five responses were dropped from the study as there were very few in number. Table 31 represents the relationship between groups and their answers to the question.

Table 31

Iteration two, the relationship between groups and why they said they succeed/failed

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Strength of materials	95	1	.136	193	1	.422	194	1	.297
2 Thickness	95	1	.450	193	1	.039	194	1	.212
3 Area around hole(s)	95	1	.395	193	1	.051	194	1	.414
4 Distribution of weight	95	1	.479	193	1	.303	194	1	.816

There was a significant difference between physics and art participants and their answer to the second ranked answer to question two in iteration two. Physics participants (30.1%) said their solution succeeded or failed because of thickness, 14.9% of art participants said their solution succeeded or failed because of thickness. There was also a significant difference between physics and art participants and their answer to the third ranked answer to question two in iteration two. Art participants (21.3%) said their solution succeeded or failed because of the area around the hole(s), 10.3% of physics participants said their solution succeeded or failed because of the area around the hole(s).

Within iteration two, students were asked to answer the question “What’s your next idea?” There were 12 categories based on participant’s responses. The top five responses were ranked according to overall percentages and are listed in table 32 below. The remaining seven responses were dropped from the study as there were very few in number. Table 32 represents the relationship between groups and their answers to the question.

Table 32

Iteration two, the relationship between groups and what they said their next idea was

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Modify from previous	95	1	.008	193	1	.873	194	1	.001
2 Reduce material	95	1	.455	193	1	.888	194	1	.442
3 Fold	95	1	.482	193	1	.697	194	1	.235
4 No more ideas	95	-	-	193	1	.014	194	1	.013
5 Cut into V-shape	95	1	.131	193	1	.016	194	1	.811

There was a significant difference between engineering and art participants and their answer to the number one ranked answer to question three in iteration two. Engineering participants (52.1%) said they cut their solution like they did because they wanted to modify it from a previous design, 25.5% of art participants said they cut their solution like they did because they wanted to modify it from a previous design.

There was a significant difference between physics and art participants and their answer to the fourth ranked answer to question three in iteration two. Physics participants (11.6%) said they had no more ideas, 0.0% of art participants said they had no more ideas. There was also a significant difference between physics and art participants and their answer to the number five ranked answer to question three in iteration two. Art participants (12.8%) said they cut their solution like they did because they wanted to cut it into a v shape, 3.4% of physics participants said they cut their solution like they wanted to cut it into a v shape.

There was a significant difference between engineering and physics participants and their answer to the number one ranked answer to question three in iteration two. Engineering participants (52.1%) said they cut their solution like they did because they wanted to modify it from a previous design, 26.5% of physics participants said they cut their solution like they did because they wanted to modify it from a previous design. There was also a significant difference between engineering and physics participants and their answer to the fourth ranked answer to question three in iteration two. Physics participants (11.6%) said they had no more ideas, 0.0% of engineering participants said they had no more ideas.

Within iteration two participants that successfully held the weight and their answers to the question “why did you cut the materials like you did?” were analyzed. There were eight categories based on participant’s responses. The top four responses were ranked according to overall percentages and are listed in table 33 below. The remaining four responses were dropped from the study as there was very few in number. Table 33 represents the relationship between groups that held the weight and their answers to the question.

Table 33

Iteration two, participant's structures that held the weight, compared to why they said they cut it

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Based on previous	95	1	.270	193	1	.849	194	1	.228
2 Reduce materials	95	1	.969	193	1	.781	194	1	.744
3 Hole location/weight distribution	95	1	.526	193	1	.934	194	1	.467
4 Strength of materials	95	1	.278	193	1	.633	194	1	.405

There were no significant differences between groups and their answer to question one in iteration two and if they successfully held the weight.

A combination of responses to the iteration one question “What’s your next idea” and iteration two question, “Why did you cut the paper like you did” is composed in table 34. This table was compiled to observe the concurrency of ideas between iterations.

Table 34

Comparison of iteration one, participants next idea and iteration two, participants reason for cutting

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
Combination of idea and why cut	95	1	.018	193	1	.697	194	1	.006

There was a significant difference between engineering and art participants and their combination of answers to the iteration one question “What’s your next idea” and iteration two question, “Why did you cut the paper like you did.” Engineering participants (33.3%) retained their intentions from iteration one to iteration two, 12.8% of art participants retained their intentions from iteration one to iteration two.

There was a significant difference between engineering and physics participants and their combination of answers to the iteration one question “What’s your next idea” and iteration two question, “Why did you cut the paper like you did.” Engineering participants (33.3%) retained their intentions from iteration one to iteration two, 15.1% of physics participants retained their intentions from iteration one to iteration two.

Iteration three

Within the instrument, participants weighed their solution in grams; this can be measured in a numerical value and therefore can be given a mean measurement. This numerical value is represented in table 35 by the course that participants completed the test in.

Table 35

The weight of tested solutions, reported by groups, for iteration three

	Engineering student	Physics student	Art student
Mean weight	1.41	2.15	1.94

The iteration three mean weights for students participating in the three different groups were: engineering participants 1.41 grams, physics participants 2.15 grams, and art participants 1.94 grams.

Within iteration three, students were asked to answer the question “Why did you cut the paper like you did?” There were eight categories based on participant’s responses. The top five

responses were ranked according to overall percentages and are listed in table 36 below. The remaining three responses were dropped from the study as there were very few in number. Table 36 represents the relationship between groups and their answers to the question.

Table 36

Iteration three, the relationship between groups and why they said they cut their solution

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Based on previous test	93	1	.078	186	1	.582	189	1	.004
2 Reduce material	93	1	.854	186	1	.314	189	1	.212
3 Strength of materials	93	1	.229	186	1	.139	189	1	.958
4 Hole location/weight distribution	93	1	.862	186	1	.719	189	1	.554
5 Random	93	1	.354	186	1	.937	189	1	.321

There was a significant difference between engineering and physics participants and their answer to the number one ranked answer to question one in iteration three. Engineering participants (41.7%) said they cut their solution like they did based on a previous test, 20.6% of physics participants said they cut their solution like they did based on a previous test.

Within iteration three, students were asked to answer the question “Why do you think it succeeded/failed?” There were nine categories based on participant’s responses. The top five responses were ranked according to overall percentages and are listed in table 37 below. The remaining four responses were dropped from the study as there were very few in number. Table 37 represents the relationship between groups and their answers to the question.

Table 37

Iteration three, the relationship between groups and why they said they succeed/failed

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Strength of materials	93	1	.147	186	1	.398	189	1	.345
2 Thickness	93	1	.341	186	1	.654	189	1	.118
3 Area around hole(s)	93	1	.341	186	1	.159	189	1	.847
4 Not enough material	93	1	.862	186	1	.711	189	1	.866
5 Distribution of weight	93	1	.478	186	1	.341	189	1	.051

There was a significant difference between engineering and physics participants and their answer to the number five ranked answer to question two in iteration three. Engineering participants (18.8%) said they cut their solution like they did based on distribution of weight, 8.51% of physics participants said they cut their solution like they did based on distribution of weight.

Within iteration three, students were asked to answer the question, “What’s your next idea?” There were 12 categories based on participant’s responses. The top five responses are listed in table 38 below were ranked according to overall percentages. The remaining seven responses were dropped from the study as there were very few in number. Table 38 represents the relationship between groups and their answers to the question.

Table 38

Iteration three, the relationship between groups and what they said their next idea was

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 No more ideas	93	1	.229	186	1	.016	189	1	.000
2 Reduce material	93	1	.508	186	1	.092	189	1	.383
3 Modify from previous	93	1	.132	186	1	.476	189	1	.006
4 Fold	93	1	.166	186	1	.442	189	1	.326
5 Leave more material	93	1	.596	186	1	.662	189	1	.844

There was a significant difference between physics and art participants and their answer to the number one ranked answer to question three in iteration three. Physics participants (44.7%) said they had no more ideas, 24.4% of art participants said they had no more ideas.

There was a significant difference between engineering and physics participants and their answer to the number one ranked answer to question three in iteration three. Physics participants (44.7%) said they had no more ideas, 14.6% of engineering participants said they had no more ideas. There was also a significant difference between engineering and physics participants and their answer to the number three ranked answer to question three in iteration three. Engineering participants (31.3%) said they cut their solution like they did because they wanted to modify it from a previous design, 13.5% of physics participants said they cut their solution like they did because they wanted to modify it from a previous design.

Within iteration three, participants that successfully held the weight and their answers to the question “why did you cut the materials like you did?” were analyzed. There were eight categories based on participant’s responses. The top four responses were ranked according to overall percentages. The remaining four responses were dropped from the study as there were very few in number. Table 39 represents the relationship between groups and their answers to the question if they held the weight.

Table 39

Iteration three, participant’s structures that held the weight, compared to why they said they cut it

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
1 Based on previous	93	1	.147	186	1	.816	189	1	.032
2 Reduce materials	93	1	.936	186	1	.185	189	1	.206
3 Strength of materials	93	1	.676	186	1	.263	189	1	.554
4 Hole location/weight distribution	93	1	.836	186	1	.491	189	1	.326

There was a significant difference between engineering and physics participants and their answer to the number one ranked answer to question one in iteration three and if they successfully held the weight. Engineering participants (33.3%) said they cut their solution like they did based on a previous design, 18.4% of physics participants said they cut their solution like they based on a previous design.

A combination of responses to the iteration two question “what’s your next idea” and iteration three question “why did you cut the paper like you did” is composed in table 40. This table was compiled to observe the concurrency of ideas between iterations.

Table 40

Comparison of iteration two, participants next idea and iteration three, participants reason for cutting

Factors	Engineering/Art			Physics/Art			Engineering/Physics		
	N	df	chi	N	df	chi	N	df	chi
Combination of idea and why cut	93	1	.014	186	1	.928	189	1	.001

There was a significant difference between engineering and art participants and their combination of answers to the iteration two question “what’s your next idea” and iteration three question “why did you cut the paper like you did.” Engineering participants (31.3%) retained their intentions from iteration two to iteration three, 10.6% of art participants retained their intentions from iteration two to iteration three.

There was a significant difference between engineering and physics participants and their combination of answers to the iteration two question “what’s your next idea” and iteration three question “why did you cut the paper like you did.” Engineering participants (31.3%) retained their intentions from iteration two to iteration three, 11.1% of physics participants retained their intentions from iteration two to iteration three.

Table 41 represents the mean values for each iteration of the study. These are further separated into the specific groups that were examined. Every participant’s weight is factored into the mean value, whether they were successful in holding the weight or not

Table 41

Participants weight of solutions in grams for each iteration by group

Factors	Engineering student	Physics student	Art student
Iteration one mean	3.15	3.02	2.78
Iteration two mean	1.91	2.63	2.22
Iteration three mean	1.41	2.15	1.94

Through examination of table 41, it can be said that the mean weight for solutions dropped from iteration one to iteration two and through to iteration three. While art students started with a lower mean weight in iteration one, engineering students ended with the lowest mean weight in iteration three of all three groups.

Table 42 represents the mean values for each iteration of the study. These are further separated into the specific groups that were examined. Only participants that succeeded in holding the weight are used in this mean value.

Table 42

If the solution succeeded, its weight in grams for each iteration, reported by groups

Factors	Engineering student	Physics student	Art student
Iteration one mean	2.30	2.26	1.75
Iteration two mean	1.34	1.86	1.52
Iteration three mean	.93	1.53	1.37

Through examination of table 42, it can be said that the mean weight for successful solutions dropped from iteration one to iteration two and through to iteration three. While art students started with a lower mean weight in iteration one, engineering students ended with the lowest mean weight in iteration three of all three groups of successful solutions.

CHAPTER FIVE

Discussion

The study of engineering in high schools has recently become an innovative addition to the curriculum. This movement, as any new addition to the curriculum would, comes with many questions that need to be answered. The purpose of the study was to determine the relative contribution of an engineering curriculum in the development of problem solving and thought processes. The research addresses whether or not there is a difference between students in a non-technical class (art students) and an engineering class as well as a general physics class with regards to how they solve a structural problem within three iterations.

Two-hundred-fifty junior and senior students enrolled in engineering, art and physics classes were asked to attempt to solve a structural problem in three iterations. The objective of the structural problem was to remove as much paper as possible, leaving the two outermost holes intact to hang the solution, while supporting a 500 gram weight. They were asked questions about how they formulated their solutions, what the results of the testing were, and to forecast or plan what they would do next.

Summary

Engineering education has the potential to make a significant and unique contribution to the school curriculum. Is the absence of engineering in secondary schools creating an incomplete curriculum? This problem is of major significance as many college programs and businesses have determined that early exposure to engineering education should start well before the freshman year in college (Sheppard & Tsai, 1992). An engineering education program at the high school level fills the requirements of businesses by developing a student's critical thinking and problem solving skills beyond what a math or science course expects of them.

Problem solving has been considered broadly as a higher form of learning which depends on other less complex forms of learning. It is seen as part of the process of investigation where the solution is not obvious to the researcher at the outset of the activity (Okebukola, 1992).

Engineering programs are missing in most secondary schools. Shouldn't such an obvious form of human endeavor (problem solving) be represented in a school curriculum? This form of education connects math, science, english and technology and may have a profound effect on how students view their educational experience. "Engineers apply the theories and principles of science and mathematics to solve technical problems. Frequently the engineer's work makes the connection between scientific discovery and real-world application" (Deal, 1994, 15). These hands-on courses should be created and implemented at the high school level with student success in mind.

Without the study of engineering the schools overall attempt to produce a student with complete critical thinking and problem solving skills is incomplete. A major problem of secondary education is that schools teach science, technology, and mathematics only in the context of the specific disciplines.

Engineering education makes a contribution to the high school curriculum by providing an opportunity for students and teachers to link content together and apply it to solve problems. Many colleges and universities are still not attracting and retaining students in engineering programs. "Too many students become discouraged in the first few terms of an engineering curriculum and because of inadequate exposure to engineering and engineering design, many switch out of engineering" (Sheppard & Jenison, 1996).

Without the study of engineering the schools overall attempt to produce a student with complete critical thinking and problem solving skills is incomplete. Secondary education

teaches science, technology, and mathematics in the context of the specific disciplines. Teachers rarely incorporate cross curricular or concurrent experiences for their students. Cooperation formally between teachers or subjects usually does not happen for a number of reasons. The lack of common planning time amongst teachers limits the amount of sharing that can lead to the success of an integrated experience. School district allocation of teacher resources and facilities may also hinder the ability for multiple teachers to coordinate their efforts toward a common goal. Many teachers also cite the pressures to teach to a uniform state required test in their content areas as a reason for not implementing more integrated curriculum. Kelly, an anonymous teacher from California, says:

At this point, every state has testing horror stories. I have no problem with measuring my students' progress and using that measurement as a tool to help them progress. But first I want meaningful, non-politically driven measures that I can trust. Then, I want to see "high-stakes" taken out of the process. I don't think improvement happens through threat, fear, or bully tactics. The last decade's focus on high-stakes testing as a measure of accountability has disempowered teachers. You don't get powerful performance from the disenfranchised or the disempowered. You don't get powerful results from students with strong-arm tactics. I think the "No Child Left Behind" legislation will eventually prove to be the proverbial straw on our backs, and the whole thing will begin to unravel. The sooner the better for us all. (Anonymous, personal communication, January 7th, 2003).

Engineering education can be offered to a wide population within the school.

Valedictorians can learn beside special education students and develop many "soft skills" by doing so. Average students can succeed along with "at risk" students. These types of courses can offer answers to the proverbial question asked by students in math or science courses "When

am I ever going to use this in my life.” An integrated course like engineering at the high school level enhances the current or traditional system. This is true only if content in engineering courses builds on information and content presented in other courses in the school and applies it to solve real world problems and case studies. A high school engineering course will not work if a science, math or technology teacher renames a class to engineering and then teaches something other than actual engineering practices. Teaching engineering education in secondary schools is also better than having no engineering education at all.

Methodology

The research that was conducted was comparative in nature. Experimental research was not used because it was not feasible to randomly assign participants into groups; they had already been assigned to groups based on the courses they enrolled in. The research studied junior and senior students that were enrolled in general physics, engineering and general art classes. All participants were given required consent forms to have signed by a parent or legal guardian. Those students who agreed to be a part of the research participated in the study during the 18th week of semester one, 2003-2004.

Research design

The dependent variables observed included weight of tested solutions and several areas that were examined on a secondary question sheet of paper for each solution that students designed. These were:

1. Why did you cut the paper like you did?
2. Why do you think it succeeded/failed?
3. What's your next idea?

Each response was categorized and then ranked in order of their percentages. The top responses were ranked and then used in the charting of results in chapter four. The responses with very low or no percentage totals were dropped from the analysis as there was little or no data to evaluate.

Subjects

The two hundred-fifty participants involved in this research were students enrolled at Madison West High School in Madison, Wisconsin. General physics students were selected as they are taught theory in scientific principles. Engineering students were selected, as they are taught the application of theoretical and factual science while infusing technical information and the freedom to be creative in idea generation. Art students were selected to provide information on what abilities students have that are not taught scientific and mathematical theory or their applications. Art students are taught that there can be freedom in idea generation and are shown that they can go beyond what has been done or known and make something on their own.

Limitations

The findings were appropriate to those in the population for which the sample was taken. If other high schools within the state of Wisconsin and throughout the nation have similar school structure and classes, the results may be applicable.

Summary of findings

Physics and art students did not take engineering classes. Physics students are typically “academic” in nature and they are taking many different courses throughout the day and may not have room for another elective, or not see the need for another elective. Art students are already taking their elective and may have rigorous schedules as well. While some dabbled in one engineering course, the majority didn’t (see table 14). Betsy Barnard, who was the supervising

physics teacher in this investigation, said in a post test interview “Physics students are given tools for thinking with an order to articulate their ideas better” (B. Barnard, personal communication, March 8th, 2004). Physics students are taking a theoretical course that teaches many key concepts and processes that are applied in another course called engineering. It is therefore recommended that students who take a physics course also take a case study based engineering course to further their knowledge base and experience by applying the materials learned in physics class along with new concepts, techniques and processes that can develop them into better problem solvers.

Successful completion of design problems requires that the students meet criteria while addressing conflicting constraints. Where constructions are involved, these might draw on technical skills and understandings developed within the science program, technical and craft skills developed in other school work, or require developing new skills (National Committee on Science Education Standards and Assessment, National Research Council, 1996).

Phil Lyons, the supervising art teacher in this investigation said in a post test interview “Art students are given problems or parameters for an assignment and they have to try to answer the question. The instructor sets the boundaries but the students are allowed to go outside the boundaries” (P. Lyons, personal communication, March 8th, 2004). The same can be said about engineering students and their instruction. Engineering students are taught not only about the product or final solution, but also about the process or the journey taken to the final solution.

Most textbooks present “problems” that can be solved without thinking about the underlying mathematics, but blindly applying the procedures that have just been studied. Typical classroom instruction subverts understanding even further by providing methods

for solving problems that allow students to answer problems correctly, without making an attempt to understand them (Schoenfield, 1988, 163).

Real world problem solving involves an understanding of the complex interaction among various fundamental sciences, environmental, social, economic and ethical issues as well as computationally based analysis and design. Teaching students to think in a manner that would encompass these issues is needed at all levels of education (Powers, 2003).

These are all key concepts in teaching an engineering course. It would therefore benefit an art student to take an engineering case study course in order to transfer the techniques, concepts and processes they learned into a class where society's desires as well as problems are solved. "Students need to be given exposure to the creative nature of engineering through design projects, hands-on laboratories and open-ended problem solving" (Sheppard & Jenison, 1996).

Students may believe that an engineering course is specifically for only those interested in engineering as a career, it is not. An engineering course's theme is that of problem solving and thought processes. An engineering course has the ability to take what is learned throughout all courses in the school curriculum and apply that information to solve real world problems. It is important that physics and art students begin to realize that this is an opportunity to use both their creativity along with their theoretical background skills and meld them together while demonstrating problem solving abilities. If they lack the creative, technical or theoretical backgrounds, an engineering course can fill in the missing information and enhance the learner's intellectual toolbox.

Physics and art students didn't use calculations to solve their problems. Engineering and physics students have completed a higher level of math course than art students, however physics students did not transfer any knowledge from math courses they had taken and apply it to solve

this problem. Most physics and art students don't have opportunities to bring in things that they learn in other classes and apply them. They also may not be taught that they can transfer the knowledge of their experiments in physics or their creative study in art into other contexts. This may be an opportunity for physics and art instructors to specifically implement instructional techniques to foster a student's ability to transfer knowledge into and out of physics and art classes. Many classes in our education system teach facts to students and then expect them to regurgitate them back on an assessment a few days later. These facts, when taught in a contextual or applied manner may stay with a student longer and become more meaningful to them, thus intrinsic and automatically stored in their brain in an organized, connected manner so that they can readily retrieve the information at a later date.

Engineering students used sketching more than physics students to plan out how they were going to solve the problem. This is most likely due to engineering student's exposure to the design and problem solving process in the engineering courses. Engineering students are taught through the use of brainstorming and thumbnail sketching that this is the correct procedure in solving problems. All ideas need to be put on paper and then the best of these different ideas should be used to progress in the right direction, eventually leading to a solution. "Physics students are exposed to problems, but seldom have chances to attempt open ended problems or true design problems with materials" (B. Barnard, personal communication, March 8th, 2004). These students therefore do not have the opportunity to plan using sketching. It is to be noted that there is almost significance to the difference between engineering and art students regarding sketching as well (see table 23). Physics students and their instructors should not attempt to integrate the design and engineering problem solving methods into their classrooms as it would

take away from the content that is critical to the definition of what a physics class is. The American Heritage Dictionary of the English Language, Fourth Edition defines physics as

The science of matter and energy and of interactions between the two, grouped in traditional fields such as acoustics, optics, mechanics, thermodynamics, and electromagnetism, as well as in modern extensions including atomic and nuclear physics, cryogenics, solid-state physics, particle physics, and plasma physics (Houghton Mifflin, 2000).

It is however recommended that physics students take the opportunity to engage in the design process and engineering problem solving methods by either taking an engineering course, or participating in an extracurricular activity or session that has these two elements as their theme.

Physics students complete chemistry more than engineering students. This is logical because physics students are in a course sequence where chemistry precedes physics. Ninety percent of physics students took chemistry. If you combine an engineering student's level of chemistry and physics, it amounts to 90% as well. Nine out of ten engineering students take chemistry or physics and nine out of ten physics students take chemistry and will complete physics. However it can be seen that engineering students complete higher level math courses than physics students and can transfer the knowledge they gain in math and physics into a new context like an engineering case study or experiment. This suggests that engineering students reference content they learn in math and physics whereas physics students may not.

Engineering and physics students complete higher levels of math and science than art students. Physics students may or may not take engineering but are prepared theoretically and mathematically, more than art students, for an engineering course. However, when it comes to

the creativity associated with an engineering course, this research shows that clearly art students have the tools to be prepared for an engineering course. There may not be a perceived need for an art student to take higher-level math and science courses when enrolled in a creative elective like art. They may not know or haven't been shown that there is a class, engineering, that can help them apply the skills learned in higher levels of math and science. It may be that the art students need to brush up a little on technical or theoretical concepts, and a physics student needs to re-familiarize themselves with their creative exposures in school and life to be more successful in an engineering course. This is where a teacher that is properly trained to teach an engineering course can help these students.

Engineering students complete a higher level of math than physics students. Engineering students may be more focused in using the math in an application like engineering or may want to have a higher level of math because of future education plans that they wish to pursue. This may also have a connection with another significant finding that engineering students used calculations to aid in their solution of their problem and physics students did not. The absence of calculations amongst physics students may be because engineering students have higher-level math skills available than physics students to transfer to the problem.

Physics students had a higher grade point average (GPA) than art students. This can be linked back to the finding that physics student's complete higher math and science course work than art students, and therefore are more academically predisposed. This is only defined into specifics within what was examined in the study, rigor of coursework and history of classes were not examined. Physics students did not necessarily apply the information that they learned in their coursework to this problem, even though they had a higher GPA and higher level of math and science than art students. Physics and art students had difficulty transferring things they

have learned into a new context like this problem or within its iterations. Just because a physics student has a higher GPA than an art student does not mean that they are going to solve the problem better than the art student or be able to transfer knowledge from other coursework to new contexts.

More females take art and physics than take engineering. This is a trend that echoes what businesses and colleges are currently experiencing and have been experiencing. Research suggests that females typically do not take technically oriented classes.

On the whole, women comprise just over 9 percent of the nearly twenty-one thousand tenure tracked and tenured engineering faculty in the United States. Their representation stands at 4.7 percent at the full professor level, while increasing to 11.5 and 17 percent at the associate and assistant professor levels, respectively. Women earn engineering degrees at between 17 and 22 percent at all degree levels (Gibbons, 2003, 1).

In this study, females took a creative class (art) and theoretical class (physics) but not a creative technical class (engineering). Colleges and universities have realized the role of females in their schools and are working hard to bring more females in to their classes. It is important for the high schools to improve upon this as well. Students and counselors may think that teaching engineering is completely vocational, it should not be in secondary education. Engineering at the high school level should be an arena where problem solving and thought processes are taught. Not every student is going to become an engineer they simply need the problem solving skills for life. Females need to be included in the teaching of the problem solving and thought process in order to provide them the complete experience at the high school level.

Engineering students were more concerned than physics and art students with hole location and weight distribution in iteration one. This was amongst all solutions designed by

students and solutions that successfully held the weight. Engineering students completed a higher level of math than physics students but an equal amount of science as physics students. Similarly the engineering students had a higher level of math and science than the art students. Engineering students have shown through their coursework that they can use knowledge learned from other courses to solve problems, so therefore they transfer the information from their math or science course into their description of why they thought their solution succeeded or failed. It is because of this coursework in engineering that engineering students said that their successes on this project were based on the science and math behind it rather than shot gunning (shooting from the hip or a random idea) an attempt to solve the problem. Just because a physics student does well in physics classes, they may or may not transfer that knowledge until a formal process (engineering) prompts them to do so. "Thinking skills are thought to be general in nature and can be transferred beyond the context in which they are acquired" (McGuinness, 1993, 306). This means that students in any course can access their previous experiences and transfer them to the opportunity to create a solution or solve a problem. Physics and art curriculum may need to implement some kind of formal education regarding the transfer of knowledge from one context to the next.

When it came to what their next ideas were in iteration one, art students worried more about reducing materials or folding materials than engineering students. Art students were more concerned about the materials than engineering students. An art student's creative course has a great deal to do with materials and not much with the technical aspects of those materials. Engineering students have the technical and theoretical background to understand why the materials act like they do, but are more concerned with the actual process and modifying their new idea from a previous experience more than art students or physics students. Engineering

students more than art or physics students wanted to base their next idea off something that they have done previously. Why wouldn't physics students transfer the knowledge gained in one iteration of this study to the next? This is most likely because physics students are "taught to choose a strategy, try it out, see if answer makes sense, try a different strategy and see if the answers agree" (B. Barnard, personal communication, March 8th, 2004).

Students were asked about why they decided to do what they did in iteration two. Engineering students based their design off a previous design more than physics students. Engineering students are taught to use the knowledge gained from one place and bring it to another, whether it be from courses in their schedule or any experience in life. Physics students are not necessarily shown the opportunity to use information gained from another place into their studies. The educational system assumes that this transfer in physics is happening automatically with no prompting. Physics students may be more concerned with "getting it done" than actually basing their next solution off of something that they have done already.

In iteration two, physics students more than art students thought that their solution succeeded or failed because of thickness. This is interesting as now physics students were starting to think more about material and have an idea about structure as well as doubling up materials rather than a single layer. We may now see a bit of the physics education coming forward in the students' comments about thickness and therefore structure. This may be based on what they saw in iteration one. Iteration one's results may have led them to believe that they needed to increase the thickness.

Students in iteration two were also asked what their next idea would be. Engineering students again said they based their next idea off of previous designs. This is a theme running through this study in that engineering students habitually transferred knowledge and based their

ideas off of previous experiences, applying things that they learned to the problem at hand versus physics or art students.

To reflect is to look back over what has been done so as to extract the net meanings which are the capital stock for intelligent dealing with further experiences. It is the heart of intellectual organization and of the disciplined mind (Dewey, 1947, 110).

That is not to say that physics or art are not important or not as good as an engineering course, but that they are unique and significantly different. An art class is very important because it develops student's creative abilities. A physics course is very important as it develops student's theory base. The educational system needs to have a place where these two practices of creativity and theoretical skills can combine such as an engineering course. We can then show students that there are opportunities to transfer knowledge that is learned in one course into another and then into a new context altogether. "Contextual learning, according to John Seely Brown, is perhaps the condition most overlooked in school; yet, recent studies are showing that we learn most when we learn in context" (National Council on Vocational Education [NCVE], 1991, 58). Students should be able to base their decisions off of things that they have experienced in the past or knowledge that they have gained prior so that they can create the correct "educated guess" and possibly create the correct solution for a problem. There was an unanticipated finding in that 11.6% of physics students reported that they had no more ideas at the end of iteration two. No student in engineering or art reported that they had no more ideas at the end of iteration two. It could be that students that take creative or creative technical courses enjoy working with open-ended questions that involve materials more than students that take only a technical course with no creative content within them. It was also an unanticipated finding that 12.8 % of art students said they cut the solution into a "v-shape" versus 3.4 % of

physics students. A v-shape solution suggests some kind of vector analysis might have been going on in the art students mind, even if were only subconsciously. The physics student has been taught vectors and structures and did not choose to use their physics education as a basis for their solution where as art students may have. As was suggested previously, physics and art student's curriculum should be enhanced or supplemented in such a way that they grasp the importance of basing decision off of historical or previous experiences and not just shot gunning the answer.

In iteration three, engineering students more than physics students said that they based their idea on previous designs. Comparing engineering and art students on the same question, there was almost a significant difference (.078). Engineering students that successfully held the weight in iteration three said that the reason for their success was because of weight distribution. Physics students are being taught physics and distribution of weight, etc. but not citing physics reasons for the success of their solution. Amongst these same solutions that held the weight in iteration three, engineering students said they based their idea on previous designs more than physics students. Again this reaffirms the theme regarding engineering students and their thought processes throughout the study. Historical information or previous experiences play a big part in how engineering students think.

In this same iteration, students were asked what there next idea would be, even though there wasn't another opportunity to design it. Engineering students, more than physics students stated that whatever they designed, it would be based on what they had done previously. More physics than art or engineering students said that they had no more ideas. Art and engineering students did express ideas for a next solution if they had the chance. Physics students may be more concerned with "getting it done" than actually learning through the process. This can be

based on the philosophy of most physics courses in that physics students do not get chances to do multiple iterations of the same experiment because of the lack of time to do it in their class. This tells us that physics students typically work to finish the experiment or the task at hand and may learn through the process, but are subject to strict timeframes for completion and that is where the thought process or teaching ends, upon their completion of the experiment. In their experiments, physics teachers and students are more likely interested in getting finished with an experiment, than being able to connect the experiment with a process, a new idea, or another experiment. This would explain why in this study physics students did not base their ideas off of previous experiences. While the information presented in a physics class may be consecutive, it may not be cumulative enough to prompt these thoughts. Engineering students are more concerned about the process they are going through, as is evident through their comments that they based their current idea and next ideas on previous experiences. Students need to be encouraged to forecast and foresee where the current task or lesson will be taking them. We cannot completely endorse education's regurgitation mentality if we hope to foster the complete student and a higher level of problem solver in our high schools and even into our technical colleges and universities. Within a course, objectives should be written to help the student see where the tasks fit in the big picture of the course and into our society or workplaces. By doing this, we may be able to foster ideas of growth, continued learning and the expansion of knowledge.

When mean weights of solutions were compared, amongst all solutions in iteration one, engineering students started with the heaviest solution and art students were the lightest. However, because engineering students base their ideas off past experiences, as evident in this study, their second and third iterations of all solutions and solutions that held the weight, dropped in weight each time and were the lightest of all three groups overall. Physics student's

solutions started lighter than engineering students however were the heaviest in iteration two and three. It was unexpected, and unanticipated that the art students, without theoretical education like a physics class or a creative technical course like engineering, did better than physics students in mean weights of all solutions and mean weights of solutions that held the weight. This may be because art students are used to working with materials creatively and being able to apply different techniques to different situations. Art students may also have a high capacity for taking creative risks. These procedures used by art students are not necessarily technical in nature, but they are able to use materials to “do things” whereas physics students complete experiments and don’t get the chance to design the experiments with materials or do open-ended problem solving.

When all participants were compared on their ability to carry ideas forward from one iteration to the next, engineering students carried their ideas forward from iteration one to iteration two more than physics or art students, and from iteration two to iteration three more than physics or art students. What can be derived from this study is that engineering students carry forward their ideas from the planning stages to the development stage of an idea. “The principle of continuity of experience means that every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after” (Dewey, 1947, 27). Engineering students also therefore have more concurrent thoughts than physics or art students. This is important because thought processes should not be random and should be properly planned as well as executed. This ability to carry ideas forward, along with the theme that engineering students demonstrated through this study of basing ideas off of historical evidence or previous experiences, provides evidence for why engineering courses make a unique and significant contribution to the educational system.

Recommendations

A study needs to be initiated on students and their habits, courses they take, course rigor and scores on state tests for courses within this study.

A gender study needs to be done at the high school level reporting the reasons why females take elective creative courses, theoretical courses that are required, but not elective creative technical courses.

Physics students that are interested in engineering endeavors should strive to take a higher level of math than is required for their scheduled course.

It is recommended that students who take a physics course also take a case study based engineering course to further their knowledge base and experience by applying the materials learned in physics class along with new concepts, techniques and processes that can develop them into better problem solvers. Physics students should take the opportunity to engage in the design process and engineering problem solving methods by either taking an engineering course, or participating in an extracurricular activity or session that has these two elements as their theme.

Further study needs to be done regarding why art and physics students tend not to carry their ideas forward from the planning stage to the execution stage.

Art and physics curriculum may benefit from some kind of formal education regarding the transfer of knowledge from one context to the next.

Physics students and their instructors should not attempt to integrate the design and engineering problem solving methods into their classrooms as it would take away from the content that is critical to the definition of what a physics class is.

If we are to provide a science education which is genuinely vocational, then we must be clear about what those who work in science or science-related employment actually do....There is also likely to be a core of generic skills which is common to all science-based industries. We refer here not to the generic or 'key' skills which have already been defined, namely communication, information technology, numeracy and 'working with others', but to generic *science* skills (Gott, Duggan &, Johnson, 1999, 97).

It may be that these courses need to be accredited or certified by the engineering society in order to keep instructors from changing their class names to engineering and actually doing something very different.

Research conclusion

Shouldn't such an obvious form of human endeavor (problem solving) be represented in a school curriculum? What we do need to assure is that our students evolve and grow with enough knowledge to be viable employees and informed citizens. Our curriculums have to reflect the thoughts and needs of the communities we live in and the businesses that reside in those communities.

Schools spend a great deal of time teaching facts outside the context of inquiry. Students spend much of their time memorizing such facts, which they promptly forget after tests.

If the inquiry genuinely matters to students, they will seek out the facts and remember them long after the problem has been solved (Mina et al., 2003).

These facts, when taught in a contextual or applied manner may stay with a student longer and become more meaningful to them, thus intrinsic and automatically stored in their brain in an organized, connected manner so that they can readily retrieve the information at a

later date. Suddenly, education looks more like it should, a cooperative effort to supply students with the best experiences possible, utilizing every resource possible, including other teachers.

The findings of this research tell us that engineering students can attack problems with a higher credibility than physics students and better than art students. An engineering course is unique in nature and contributes significantly in the development of problem solving and thought processes. Secondary school curriculum is intrinsically incomplete in its pursuit of the development of students thought processes in the absence of the study of engineering. This research is a small piece of evidence. In order to validate and reiterate these findings, many more studies that replicate this study need to be undertaken.

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APPENDIX A

Consent form

Alan G. Gomez, a student of the College of Technology, Engineering and Management at the University of Wisconsin-Stout is conducting a research project for thesis class TECED-770 for Industrial/Technology Education. This research is titled "Hands on problem solving skills". Participation is voluntary and may be ended at any time during the research

Your child's class has an opportunity to take part in the study though a simple, one hour activity using scissors and paper to create a design that will hold the most weight without breaking. The study will replace one classroom period of instruction, however it is designed to enhance the content that is being taught within the course in the 8th week of classes. Students that choose not to participate will have an alternative assignment for the given hour that covers similar material that will be selected by the instructor of the class. A debriefing session may or may not be scheduled by the instructor of the course for the day following the study. Students that chose not to participate would be involved in that debriefing using the alternative assignment they completed during the study.

Because the study is anonymous, feedback for students will only be in the form of their strength to weight ratio for each design they tested. Students within the classes participating will be given the results of the study in order to compare their individual strength to weight ratios to the findings on or about February 1st, 2004. The results of this study will also be disseminated at the Wisconsin Technology Education Associations Annual Conference at Chula Vista Resort in Wisconsin Dells, WI on March 4th, 2004 at 10:30AM. Any student or parent that needs translation of the study, or the results, will be supplied with that information provided they indicate that it will be needed on this consent form. Your student's performance will *not* influence his/her grade in the course. This research will benefit the schools coursework as it may identify critical course combinations that enhance a student's problem solving skills.

The Madison West High School science department, the technology department, art department and the principal's office have approved this project. I am asking your permission for your child to be included in this study.

It is not anticipated that this study will present any medical or social risk to your student. The information gathered will be anonymous in nature and any reports of the findings of this research will not contain your students name or any other identifying information.

Please sign and return this form, keeping the enclosed copy for your records, to the instructor of the course it was handed out in by September 12th, 2003.

Questions or concerns about the research study should be addressed to Alan G. Gomez, the researcher, (608)-204-3078, agomez@madison.k12.wi.us, or Dr. Kenneth Welty, (715)-232-1206, weltyk@uwstout.edu. Questions about the rights of research participants can be addresses to Sue Foxwell, Human Protections Administrator, UW-Stout Institutional Research Board for the Protection of Human Subjects in Research, 11 Harvey Hall, Menomonie, WI, 54751, phone (715)-232-1126.

Thank you for your time and support. Please don't hesitate to call or email with your questions.

Sincerely,

Sincerely,

Alan G. Gomez
Researcher

Kenneth Welty
Research Advisor

I do / do not (circle one) agree to allow my child, _____, to participate in this study.
(Child's name)

Signature _____ Date _____

APPENDIX E

Instrument

INSTRUCTIONS PAGE

The objective of the test is to remove as much paper as possible while supporting the given weight. The end result will be strength to weight ratio of the provided 500 gram weight to the weight of the paper structure created.

1. Your proctor will distribute envelopes that contain three different sets of colored paper, make sure that the codes on the papers are all the same and match the code on the front of the envelope.
2. Your proctor will have testing apparatus', scissors and pencils for you to use during the test. Insure that all items are in good condition and exchange any as necessary.
3. Fill out the 7-question survey BEFORE you begin the test.
4. The green set of paper is for your first trial. The yellow set of paper is for your second trial. The red set of paper is for your third trial.
5. The codes at the top of the paper must be visible when you are finished. If you have removed the code, or cut it, please re-write the code on your final product.
6. You must leave the two punched holes at either end of the paper INTACT, as this is where it will be hung on the apparatus.
7. Answer the three questions on the last page BEFORE you go on to the next try.
8. You must weigh your solution (in grams) and record it BEFORE you hang it on the apparatus for testing.
9. Use the provided weight for testing
10. You have 50 minutes to complete all three trials. Please return ALL paper to the envelope provided, even if they are scraps.

**RECORD THE WEIGHT OF YOUR PAPER STRUCTURE
SOLUTION FOR THIS TRIAL**

_____ Grams

Use this sheet of paper to construct your solution-MAKE SURE THE CODE AT THE TOP OF THIS PAGE IS WRITTEN ON YOUR SOLUTION

ANSWER THE FOLLOWING QUESTIONS BEFORE YOU MOVE ON TO THE NEXT TRIAL

Why did you cut the paper like you did?

Why do you think it succeeded/failed?

What's your next idea?

APPENDIX F

Madison West High School description

Madison West high school is located in the city of Madison, Wisconsin. The city of approximately 213,679 is the location of the state capitol and is the largest site of the University of Wisconsin. Madison has long been considered a leading cultural and educational center of the Midwest. West High School is a comprehensive four-year high school with a current enrollment of 2,160. West was awarded a "School of Excellence" award in 1985 by the U.S. Department of Education and is accredited by the Wisconsin State Department of Public Instruction and by the North Central Association. West High School's students come from various social, economic, and cultural backgrounds; however, the majority are from business and professional families. Located near the University of Wisconsin, West has a large international population. Approximately 34% of the students are students of color (21 Native American, 194 Hispanic, 225 Asian, and 305 African Americans).

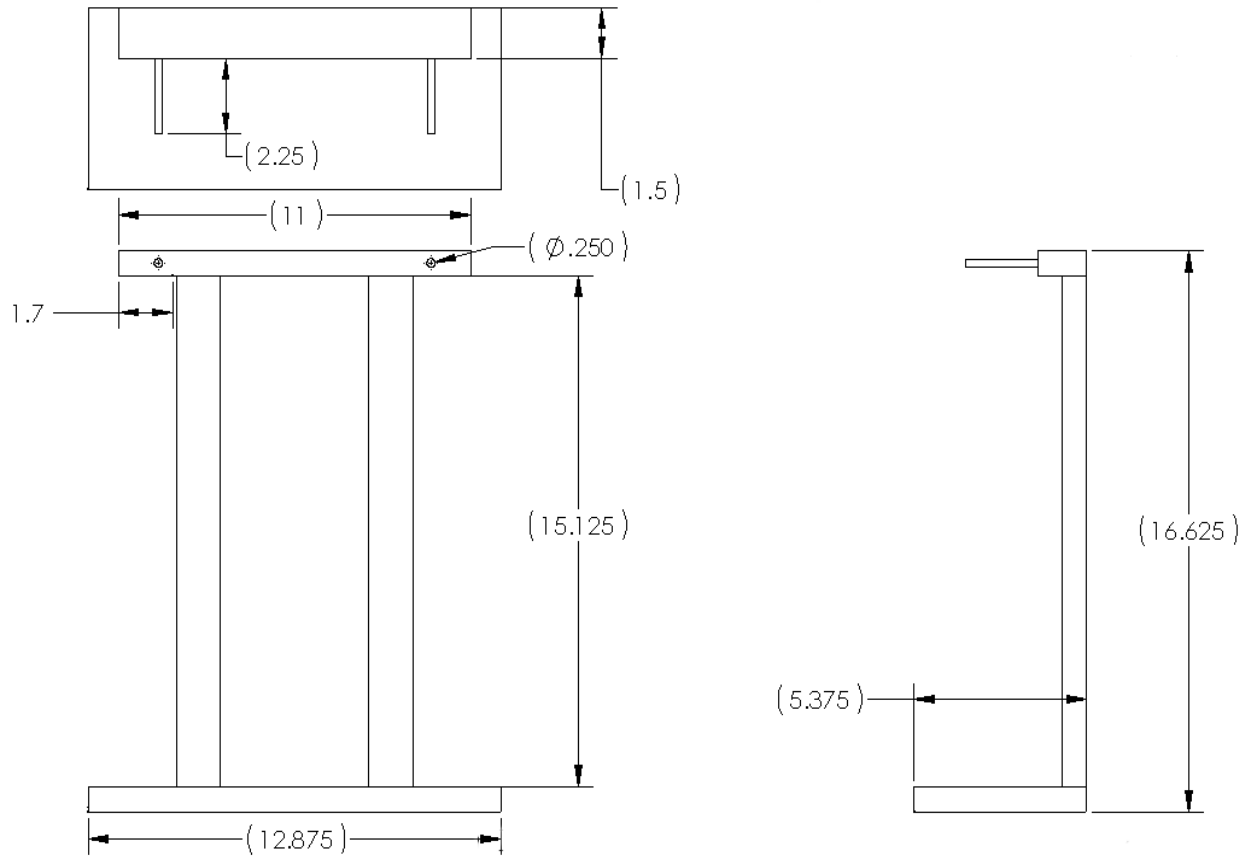
A total of twenty-two credits are required for graduation including the following: four credits of english, three credits of social studies, two credits of mathematics, two credits of science, one and a half credits of physical education and one half credit of health. Students may elect to include physical education in their grade point average (GPA). Grades are not weighted for Accelerated, Honors, or AP courses.

In addition to 13 interscholastic sports, 70 extramural activities and a wide range of performing arts productions, more than 30 extracurricular organizations provide a wide variety of activities that enrich the West High School experience. Ranging from the nationally recognized Science Olympiad team, to DECA, to Fine Arts Week, to multi-cultural retreats, the activities program reaches every student.

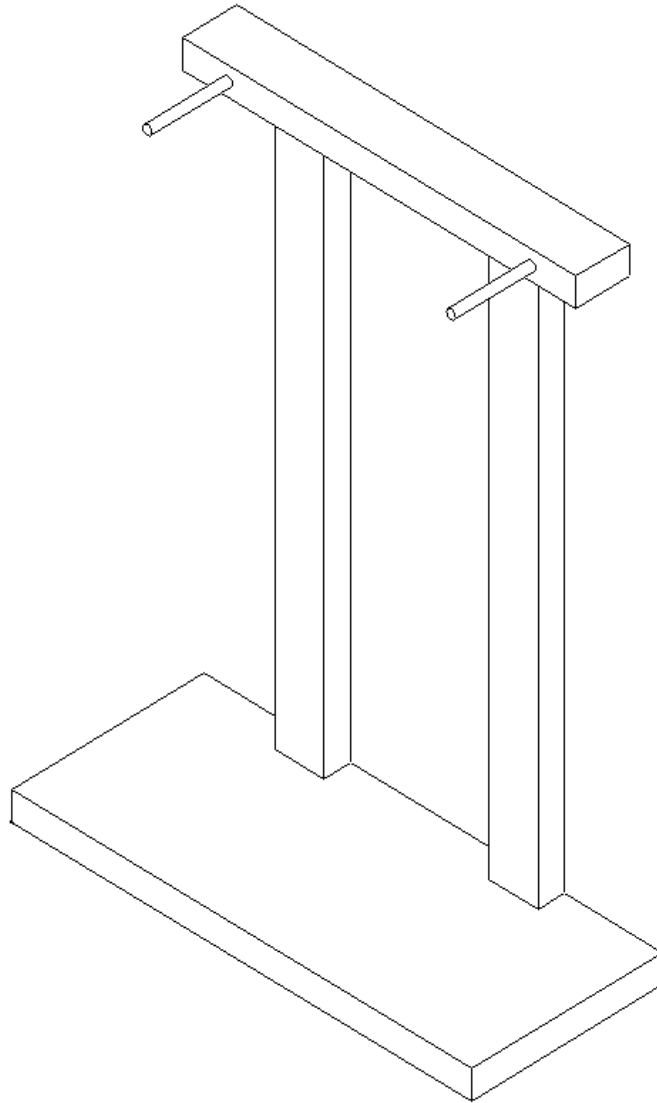
The National Merit Scholarship Corporation named 24 seniors from the Class of 2002 as semi-finalists, and all 24 went on to become finalists. Two seniors were named National Hispanic Scholar semi-finalists, and 2 seniors were named as National Achievement Scholarship Program finalists. Madison West High School also had 12 Commended Students (Madison West High School, 2003).

APPENDIX G

Apparatus design



The apparatus design used in the test.



An isometric drawing of the apparatus used in the test.